31 January 2000

MEMORANDUM FOR RECORD

FROM: John D. Cunningham
System Program Director for the
Integrated Program Office

SUBJECT: Cost, Operational Benefit, and Requirements Analysis (COBRA)

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Cost, Operational Benefit, and Requirements Analysis (COBRA) Final Report consists of the initial report, two updates, and a report to Congress:

1. Final Phase 0 COBRA report and appendices, 1996

2. Update - Executive Summary and attachment, 1997

3. *Report on Polar Convergence Operational Benefits and Cost Savings*, 1998

4. *Civil Benefits Report*, 1998

This report is made available for information only. The following points should be kept in mind:

1. The NPOESS COBRA represents the Government's NOTIONAL NPOESS system at the time the report was generated;

2. Some Environmental Data Records (e.g. SESS) and system requirements have changed since these reports were written;

3. Government Cost Data has been deleted from this public release.

Please contact the Data Manager at datamanger@ipo.noaa.gov if you have any questions about these reports.

June 11, 1996

Dr. Paul G. Kaminski
Under Secretary for Acquisition
and Technology
Office of the Secretary of Defense
Room 3E933
1000 Defense Pentagon
Washington, D.C. 20301-1000

Dear Dr. Kaminski:

I am pleased to submit the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program's Cost, Operational Benefit, and Requirements Analysis (COBRA) Final Report. I am particularly pleased with the interaction and cooperation that the Integrated Program Office has had with the Joint Agency Requirements Group, the Senior User's Advisory Group, and the rest of the DoD, NOAA, and NASA user communities during the development of the NPOESS Integrated Operational Requirements Document (IORD-1) and the COBRA Alternatives.

We have complied with both the letter and intent of the "Guidance for Phase 0 COBRA for the NPOESS Program" issued by you on 14 November 1995. As the report shows, the COBRA team evaluated four alternatives which allowed cost to vary as an independent variable across a two billion dollar range. Alternative 2, which establishes the basis for the NPOESS funding line, not only saves the $ 1.3 billion set as a goal by the National Performance Review and the COBRA Guidance, but also satisfies <u>all</u> of the NOAA and DoD requirements for the 2005 timeframe (IORD-1 requirements) at the "threshold" level.

The COBRA will be updated prior to Milestone I, based upon the knowledge gained by the IPO over the next three years. In the meantime, I would be happy to review the current COBRA findings with you at your convenience.

Sincerely,

James T. Mannen
System Program Director
Integrated Program Office

Enclosure

DISTRIBUTION

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NASA (Gen Dailey)
SUAG Members:
- NOAA/NESDIS (Mr. Winokur)
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- DoD/N096 (RADM Tobin)
- DoD/XOW (BGen Lennon)
- DoD/AFSPC/DO (BGen Cook)
- NASA/MTPE (Dr. Harriss)

JARG Members:
- DoD (Maj. Bedard)
- NOAA (Mr. Hawkins)
- NASA (Mr. Cote)

ASA(RDA) (Mr. Norris)
ASN(RDA) (Mr. Smith)
DUSD(Space) (Mr. Davis)
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- Dr. Zimmermann

IPO

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

INTEGRATED PROGRAM OFFICE

FINAL PHASE 0

COST AND OPERATIONAL BENEFITS REQUIREMENTS ANALYSIS REPORT (COBRA)

June 12, 1996

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM

INTEGRATED PROGRAM OFFICE

FINAL PHASE 0
COST AND OPERATIONAL BENEFITS REQUIREMENTS ANALYSIS REPORT (COBRA)

June 12, 1996

Prepared by:	Approved by:
________________________	________________________
Frank H. Eastman	James T. Mannen
NPOESS Systems Engineer	NPOESS System Program Director

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EXECUTIVE SUMMARY

PURPOSE

This document presents the methodology and results of the Cost, Operational Benefit, and Requirements Analysis (COBRA) for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) program.

The COBRA was conducted in accordance with the "Guidance For Phase 0 Cost, Operational Benefit, and Requirements Analysis (COBRA) for The National Polar-orbiting Operational Environmental Satellite (NPOESS) Program", 11 October 1995 (final). This guidance was coordinated with National Oceanic and Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA) members of the NPOESS Overarching Integrated Product Team (OIPT) and forwarded to the NPOESS System Program Director (SPD) by the Under Secretary of Defense (Acquisition and Technology) (USD (A&T)) on 14 November 1995.

This analysis reflects the NPOESS program prior to rebaselining. The COBRA Phase 0 interim report was used during the development of the NPOESS Single Acquisition Management Plan (SAMP) and the Cost Analysis Requirements Description (CARD). The report is not intended as a recommendation document, but rather serves as an information source and input to the milestone decision process and, in particular to the FY96 NPOESS program review. The report will be updated prior to the Milestone I decision.

BACKGROUND

The National Polar-orbiting Operational Environmental Satellite System will result in a merger of the post-2000 operational requirements of the NOAA Polar-orbiting Operational Environmental Satellite (POES) program and the Department of Defense's (DoD) Defense Meteorological Satellite Program (DMSP) environmental-sensing satellite systems. Under the auspices of Presidential Decision Directive/National Science and Technology Council-2 (PDD/NSTC-2) dated 5 May 1994, NOAA has overall responsibility for the NPOESS program, as well as being responsible for satellite command, control, and communications operations. The DoD will have lead agency responsibility to support the Integrated Program Office (IPO) in NPOESS component acquisitions. NASA will have lead agency responsibility to support the IPO in facilitating the development and insertion of new cost-effective and enabling technologies. The first NPOESS spacecraft was originally required in 2004, but after rebaselining, is currently anticipated to be needed in 2007, assuming successful flyout of all existing DMSP and POES satellite assets. NPOESS will support United States (U. S.) Government operations well into the 2018 timeframe.

ALTERNATIVES

The objective for the Phase 0 COBRA alternative definition process was to define systems that would satisfy as many of the Integrated Operational Requirements Document (IORD) -I requirements as possible (system-level and environmental data records (EDRs)) within the cost constraints stated in the COBRA guidance as discussed below.

Per COBRA guidance and the NPOESS implementation plan, alternative definition was a user-driven process. Technical aspects of the alternative definition (architectures) process were defined in a series of summary-level cost-performance trade-off analyses conducted by the IPO Systems Engineering organization. These analyses utilized Phase 0 contractor information as well as internal IPO and other Government studies. Alternative architectures were designed for satisfaction of IORD-I requirements and were tailored through a series of iterations over several months through interaction with the users, as represented by the NPOESS Joint Agency Requirements Group (JARG). Many alternatives were generated during the conduct of these trade-off analyses to arrive at a starting point for defining the most effective cost-constrained alternatives for the COBRA, as well as to provide cost sensitivity data to the users to aid them in refining requirements for IORD-I. During this process, users/IPO agreed that the IORD-I performance was driven primarily by the space segment. Therefore, the IPO adopted a conventional architecture for the command, control, communications (C^3), and ground processing segments, sized to accommodate each space segment configuration (e.g., Domestic Satellite

(DOMSAT) communications relays versus Tactical Data Relay Satellite System (TDRSS)). Other options will be evaluated by the prime contractors in Phase I of the NPOESS program.

From these analyses, a system (Alternative 2) that satisfied the IORD-I threshold level requirements including all system-level requirements and 61 of 70 EDRs, was defined. The nine EDRs that were not satisfied are specially categorized as P^3I EDRs; these are elements of the NPOESS mission needs identified as having potentially restrictive technical or programmatic uncertainties (as a result of the Phase 0 contractor studies). The life cycle cost of this alternative was estimated to be within the specified cost constraint (i.e., $1.3B life cycle cost (LCC) savings from the combined follow-on DMSP and POES program estimated costs in then-year dollars, as directed in the Vice President's National Performance Review (NPR)). A subset of IORD-I requirements were then analyzed, guided by user priorities, to determine a minimum cost alternative to meet the most stringent cost target (i.e., $2.0B LCC savings per COBRA guidance); this system (Alternative 1) meets 50 of 70 EDRs at the threshold level plus all system-level requirements, except for system survivability (non-key). The remaining IORD-I requirements, in addition to the 61 EDRs satisfied by Alternative 2, were also analyzed to determine which EDRs could be "added" and meet the final COBRA cost target (i.e., $0.0B LCC savings). Two systems were defined and are presented as high cost alternatives (Alternatives 3A and 3B).

As previously discussed, the process of defining these systems revealed that the main cost and performance/requirements driver, once system-level requirements were met, was the space segment, specifically the payload definition. During iterations with the user, performance levels better than threshold were sometimes retained while in other instances configurations were explored that reduced performance below threshold in order to add capabilities elsewhere. Thus, the COBRA alternatives differ specifically with respect to the payload, except for Alternative 1 which also lacks system survivability. Table ES-1 presents the payload sensors for each alternative. Table ES-2 presents the 50 EDRs that are commonly delivered by all alternatives to threshold levels stated in IORD-I. Additional EDRs delivered by each COBRA alternative are presented in Table ES-3. The EDR differences between the alternatives shown in Table ES-3 are the focus of the COBRA. It is important to note that the COBRA alternative concepts presented are notional, depicting systems which could be built for the indicated costs. Contractor-developed systems proposed for Phase II/III may, or may not, resemble these systems.

Table ES-1. Alternative Characterization - Payload and Implementation

Notional COBRA Sensors	ALT 1	ALT 2	ALT 3A	ALT 3B
Visible (VIS)/Infrared (IR) Imager Radiometer	a, b, c			
VIS/IR Imager Radiometer w/Ocean Color		a, b, c	a, b, c	a, b, c
Low Light VIS Imager	a, b, c	a, b, c	a, b, c	a, b, c
Cross-track IR Sounder	b	b	b	b
Cross-track Microwave (MW) Temperature Sounder	b, c	b, c	b, c	b, c
Conical MW Imager/Sounder	a, b, c	a, b, c	a, b, c	a, b, c
Ozone Monitor	b	b	b	d
Enhanced Ozone Profiler				d
Data Collection System	a, b, c	a, b, c	a, b, c	a, b, c
Search and Rescue	a, c	a, c	a, c	a, c
Space Environmental Suite (SES)	a, b, c	a, b, c	a, b, c	a, b, c
Earth Radiation Budget (ERB) Sensor		b	b	b
Solar Irradiance Sensor		a	a	a
Radar Altimeter		a	a	a
Wind Lidar			d	
CH_4 (Methane)/CO (Carbon Monoxide) Monitor				d
CO_2 (Carbon Dioxide) Monitor				d

Based on notional system for costing purposes

a, b, c and d indicate which spacecraft a particular instrument is flying on, where
a = 0530 NPOESS orbit, b = 1330 NPOESS orbit, c = 0930 EUMETSAT orbit,
d = free-flier

Table ES-2. EDRs (50) Satisfied by All Alternatives to IORD-I Levels

IORD Ref.	EDR	IORD Ref.	EDR
4.1.6.1.1	Vertical Moisture Profile*	4.1.6.6.3	Ice Surface Temperature
4.1.6.1.2	Vertical Temperature Profile*	4.1.6.7.7	In-situ Ion Drift Velocity
4.1.6.1.3	Imagery*	4.1.6.7.8	In-situ Plasma Density
4.1.6.1.4	Sea Surface Temperature*	4.1.6.7.9	In-situ Plasma Fluctuations
4.1.6.1.5	Sea Surface Winds*	4.1.6.7.10	In-situ Plasma Temperature
4.1.6.1.6	Soil Moisture*	4.1.6.7.11	Ionospheric Scintillation
4.1.6.2.1	Aerosol Optical Thickness	4.1.6.5.1	Land Surface Temperature
4.1.6.2.2	Aerosol Particle Size	4.1.6.6.5	Net Heat Flux
4.1.6.4.1	Albedo (Surface)	4.1.6.7.12	Neutral Density Profiles/ Neutral Atmospheric Specification
4.1.6.7.1	Auroral Boundary	4.1.6.5.2	Normalized Difference Vegetation Index
4.1.6.7.2	Total Auroral Energy Deposition	4.1.6.2.3	Ozone Total Column/Profile
4.1.6.7.3	Auroral Imagery	4.1.6.2.4	Precipitable Water
4.1.6.3.1	Cloud Base Height	4.1.6.2.5	Precipitation (Type/Rate)
4.1.6.3.2	Cloud Cover/Layers	4.1.6.2.6	Pressure (Surface/Profile)
4.1.6.3.3	Cloud Effective Particle Size	4.1.6.7.13	Radiation Belt and Low Energy Solar Particles
4.1.6.3.4	Cloud Ice Water Path	4.1.6.6.8	Sea Ice Age and Sea Ice Edge Motion
4.1.6.3.5	Cloud Liquid Water	4.1.6.5.3	Snow Cover/Depth
4.1.6.3.6	Cloud Optical Depth/ Transmittance	4.1.6.7.14	Solar and Galactic Cosmic Ray Particles
4.1.6.3.7	Cloud Top Height	4.1.6.7.15	Solar Extreme Ultra Violet (EUV) Flux
4.1.6.3.8	Cloud Top Pressure	4.1.6.7.16	Supra-thermal through Auroral Energy Particles
4.1.6.3.9	Cloud Top Temperature	4.1.6.6.10	Surface Wind Stress
4.1.6.7.4	Electric Field	4.1.6.2.7	Suspended Matter
4.1.6.7.5	Electron Density Profiles/ Ionospheric Specification	4.1.6.2.8	Total Water Content
4.1.6.6.2	Freshwater Ice Edge Motion	4.1.6.7.17	Upper Atmospheric Airglow
4.1.6.7.6	Geomagnetic Field	4.1.6.5.4	Vegetation Index/Surface Type

* designates EDRs which contain attributes which have “key” performance parameters

Table ES-3. Additional EDRs Satisfied by the COBRA Alternatives

EDR Differences from ALT 1	ALT 1	ALT 2	ALT 3A	ALT 3B
Ocean/Water				
Currents (near shore/surface)		+	+	+
Littoral Sediment Transport		+	+	+
Ocean Color/Chlorophyll		+	+	+
Turbidity		+	+	+
Ocean Wave Characteristics		+	+	+
Sea Surface Height/Topography		+	+	+
Earth Radiation Budget				
Downward Longwave Radiation (surface)		+	+	+
Insolation		+	+	+
Total Longwave Radiation (Top of Atmosphere (TOA))		+	+	+
Net Shortwave Radiation (TOA)		+	+	+
Solar Irradiance		+	+	+
P^3I				
Tropospheric Winds			+	
CH_4 (Methane) Column				+
CO (Carbon Monoxide) Column				+
CO_2 (Carbon Dioxide) Column				+
Ozone Profile - High Resolution				+

\+ = satisfied to IORD-I threshold levels
P^3I = pre-planned product improvements

With respect to performance, Alternative 1 does not meet the “system survivability” (non-key) requirement and only meets 50 of the 70 IORD-I threshold requirements. Alternative 2 meets all system-level requirements, including “system survivability”, and all IORD-I EDR requirements at the threshold level, other than those specially categorized as pre-planned product improvements (P^3I). Alternatives 3A and 3B are considered to be the high cost/advanced capability alternatives since the cost of each is estimated to be approximately equal to the total amount of financial resources originally planned and programmed for the continuation of the follow-on DMSP and POES programs. Alternative 3A meets all system-level requirements and all non-P^3I EDR requirements in IORD-I plus tropospheric winds, the highest priority P^3I EDR. Alternative 3B meets all system-level requirements and all non-P^3I EDR requirements in IORD-I plus enhanced ozone and trace gases, the next level of priority P^3I EDRs. Note that four P^3I EDRs were not considered by any COBRA alternative due to technical complexity issues. These are bathymetry, bioluminescence, optical backgrounds and salinity.

EVALUATION

Cost estimates and operational benefit assessments were completed for the four COBRA alternatives. The cost data used to conduct cost/performance trade-offs in support of alternative definition were used as a starting point and refined to support development of life cycle cost (LCC) estimates for each of the four COBRA alternatives. Costs of alternative subsystems were first developed using a variety of parametric estimating tools (e.g., the Scientific Instrument Cost Model for sensors in the space segment, the System Evaluation and Estimation of Resources (SEER™[1]) model for ground segment software), program analogies, cost estimating relationships, and empirical factors. These subsystem costs were “linked together” to develop total architecture life cycle cost (LCC) estimates. A series of integrated engineering tools, linked together with data interfaces, were used. This ensured bringing together varying inputs to develop total LCC estimates that are consistent and comparable. These tools also were used to develop input for some of the parametric models used in the subsystem cost estimating process (e.g., link analysis to determine spacecraft bus mass size). LCC estimates generated were compared to the DMSP Block 6/NOAA O,P,Q, R combined cost baseline to generate final cost savings assessments.

The operational benefit assessments reflect the EDR delivery differences between the COBRA alternatives. (Lack of system survivability is also considered for Alternative 1.) The assessments consider the consequences (mission limitations and risks) of not receiving these EDRs, as defined from user information in existing documentation and one-on-one interviews. These assessments were summarized within the context of five broad functional categories (i.e., forecasts and warnings, oceans and ice, solar and space environment, climate, and military unique applications) that encompass the 14 functional areas delineated in IORD-I, Section 1.2. Assessments were completed for selected missions that must be accomplished using weather products developed from NPOESS data. Additional sensitivity analyses were directed by OSD PA&E and conducted by the IPO to show cost savings that result from reducing the requirements set.

SUMMARY OF RESULTS

Results of the cost and operational benefit analysis are provided in Table ES-4. A stop-light assessment (color ratings) is used to summarize operational benefit results for each of the five functional categories delineated. These assessments were determined by the users and should generally be interpreted as follows: “Red” was given to a functional category for an alternative if impact to one or more missions was critical due to lack of one or more EDRs (i.e., there exist severe limitations and risks in performing a mission (e.g., loss of life/property) or there is complete mission failure); “Yellow” was assessed if impact to one or more missions was not critical but some limitations and risks still exist; and, “Green” was assessed if all relevant missions were able to be accomplished without limitations and risks. Note that all military missions and related EDRs are considered under the single functional category Military Unique Applications while NOAA missions and related EDRs were considered under the remaining four categories. This allows the impact of unique service/agency risks and limitations to be delineated and understood. Total life cycle costs are also presented in Table ES-4. These LCC include development and production costs plus total operations and support costs through 2018

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[1] Galorath Associates, Incorporated Seer Technologies Division

and are presented in then-year dollars. Details of the analysis are provided in the body of this report and in the appendices.

Table ES-4. Summary of Results by Functional Category

	ALT 1*	**ALT 2 (IORD-I)**	**ALT 3A**	**ALT 3B**
Life Cycle Costs (TY $B)	**$7.1**	**$7.8**	**$9.1**	**$9.1**
Operational Benefit Functional Categories				
Forecasts and Warnings (F&W)	Yellow	Yellow	Green	Yellow
Oceans and Ice (O&I)	Yellow	Green	Green	Green
Solar and Space Environment (S&SE)	Green	Green	Green	Green
Climate (C)	Yellow	Yellow+	Yellow+	Green
Military Unique Applications (MUA)	Red*	Yellow	Green	Yellow

* Although the key system-level parameter and all key EDR attributes are met by this alternative, MUA is "Red" from a system-level perspective since it fails to satisfy "system survivability" and from an oceanographic (versus meteorological) perspective due to the severe impacts (including fatalities) that could result in specific Navy missions due to lack of currents and ocean wave characteristics at threshold levels (see Appendix G).

CONCLUSIONS

The alternatives that satisfy all NPOESS IORD-I operational requirements (system-level and EDRs at the threshold level), except P^3I EDRs, are Alternatives 2, 3A and 3B. Alternative 1 does not completely satisfy either NOAA or DoD missions. For NOAA, lack of earth radiation budget, ocean/water EDRs, and P^3I EDRs (tropospheric winds, trace gases and enhanced ozone) contribute to the risks and limitations of that alternative. For DoD missions, the lack of the ocean/water EDRs, in particular the lack of currents and ocean wave characteristics data, critically limit this alternative. Alternative 1 also fails to satisfy system survivability. As shown for both Alternatives 3A and 3B, the sensors added to satisfy P^3I EDRs are cost prohibitive, resulting in no savings for either of these alternatives as compared to the DMSP Block 6/NOAA

O,P,Q,R baseline. Technical risk and accommodation issues also need to be considered with respect to Alternatives 3A and 3B. The maturity of the lidar technology, which is needed for directly sensed/measured tropospheric wind profiles, is an issue for Alternative 3A. Phase 0 contractor studies indicated lidar-based sensor types to be high in complexity and development risk and are not yet sufficiently demonstrated from space. For Alternative 3B, spacecraft accommodation is an issue for an enhanced ozone sensor, a CH_4/CO monitor and a CO_2 monitor. In addition, performance uncertainty is high for the CO_2 monitor.[2] **Of the COBRA alternatives, Alternative 2 is the only alternative that completely satisfies the IORD-I requirements at the threshold level, except for P^3I EDRs, within the program cost constraints placed on this study.**

[2] White Paper on "Issues related to NPOESS IORD-I Potential Pre-planned Product/Process Improvements, D. Blersch, NPOESS IPO, latest revision May 1996

SECTION 1

ACQUISITION OVERVIEW

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) acquisition overview sets the context for the Cost, Operational Benefit and Requirements Analysis (COBRA). Topics discussed include mission need, threat, operational environment, analysis guidance/constraints, operational concept and operational scenarios considered.

1.1 MISSION NEED

The need for environmental information is common to both the Department of Commerce (DOC)/National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD). Although DoD and NOAA share basic observational purposes, the objectives of each agency which must be addressed via use of environmental information are markedly different since the impacts of environmental phenomena (including the need for countermeasures) on their relevant constituencies are quite different. NOAA must promote global, environmental stewardship in order to conserve and wisely manage the Nation's marine and coastal resources as well as to describe, monitor and predict changes in the Earth's environment in order to ensure and enhance sustainable economic opportunities[1] and to protect the civilian population. DoD must develop weather/environmental products for a variety of peacetime and wartime missions across the globe. In addition, DoD decision-makers must be able to avoid and/or counter specific weather and other environmental phenomena in operational situations in order to minimize risks to personnel and assets as well as have the ability to exploit this information to provide advantages to United States (U. S.) Forces in battle situations. In order to achieve these objectives, satellite information is required. Data collected by ground-based systems in insufficient in providing all the necessary data in terms of specific measurements (e.g., information on cloud tops, upper cloud layers) and in terms of observation areas (e.g., open ocean, wilderness areas).

[1] NOAA Homepage (www.noaa.gov)

The NOAA mission has both short-term and long-term components. In the short-term, warning and forecast products and services must be provided for a broad spectrum of environmental events (e.g., tornadoes, hurricanes, floods, tsunamis and geomagnetic storms) that impact public safety and the economic productivity of the Nation. NOAA's present ability to accurately predict short-term environmental change is restricted by observations that are incomplete in both time and space dimensions. This limits the ability to improve understanding, and hence, predictive modeling, of our environment. There is an urgent need for NOAA to re-invest in research components to improve its observational systems, develop a better understanding of environmental processes, and enhance predictive models and dissemination systems in a comprehensive approach for the total environment. In the long-term, high impact changes must be foreseen since decadal-to-centennial changes have enormous impacts on societies and governments, and pose critical prediction and assessment needs on a global scale. To be able to foresee both natural and human-induced changes in the environment requires predictions sufficiently credible for actions in advance of observation of the change. The need is particularly acute for environmental changes that cannot be reversed quickly (e.g., global warming from long-lived greenhouse gases). The key to such credibility lies in the completeness and rigor of research and its results. Only then can effective public policy, private sector economic strategies, and other societal decisions be made over the next several years.[2]

For DoD in the short-term, it is imperative to have environmental information with sufficient accuracy, consistency, and timeliness, as well as spatial and temporal resolution, to have a positive impact on global operations. DoD's policy is to minimize collateral damage in operational situations. The ability to eliminate risks to both personnel (military and civilian) and assets due to the existence of specific weather conditions or other environmental phenomena is critical and requires timely, quality weather knowledge due to the quick-changing nature of these situations and the narrow window of opportunity to change tactics in reaction to weather conditions (e.g., changing weapon loads). In addition, the ability to exploit the weather and space environment is crucial to providing U. S. Forces with operational advantages in a battle situation. In the long-term, the ability of the military to exploit weather and space environment

[2] Ibid.

data will be a key input to development of advanced weapon systems. In addition, long term climatological data supports logistics planning for missions (e.g., expected high/low temperatures, winds) such as site selection and layout (both temporary and permanent runway orientation at foreign airfields). DoD also has need for space environment forecasts for its communications systems, the health and safety of its spacecraft, and to resolve anomalous behavior caused by single event upsets to spacecraft electronics.

In summary, operational environmental data from polar-orbiting satellites are important to the achievement of national economic, security, scientific, and foreign policy goals.[3] In order to achieve these goals, both the DoD and DOC must have accurate, consistent, timely and global environmental information. For DoD, this data is primarily used for planning and carrying out tactical operations in various places around the globe. These operations require a constant influx/refresh of timely, accurate measurements in order to assess and respond to dynamic, quick-changing environmental situations (e.g., a sandstorm in the desert). Continual improvement in measurement ability is necessary to keep pace with technological advances in both predictive models (i.e., inputs that initialize these models must be at a level of fidelity that supports advanced models in order to be of any use) and weapon systems. For DOC, the ability to support U. S. economic and public safety interests requires keeping pace with technological advances, not only in predictive models, but in the ability to measure weather phenomena over the long-term.

1.1.1 Current Satellite Contributions to DoD and NOAA Missions: DMSP and POES

Satellite environmental data have benefited both the civilian and military sectors for over 30 years, beginning with the launch of the Television Infrared Observation Satellite (TIROS) - 1 by the National Aeronautical and Space Administration (NASA) in 1960, and the military's Defense Meteorological Satellite Program (DMSP), operational since 1965. Currently, the NOAA Polar-orbiting Operational Environmental Satellite (POES) and the DMSP serve most of today's U. S. needs for global remote environmental sensing. The NPOESS is the replacement program for

[3] Presidential Decision Directive/National Science and Technology Council (PDD/NSTC-2), Section II, 5 May 1994

the POES and DMSP follow-on systems. Appendix A presents additional historical information about DMSP and POES.

Improvements to TIROS (later the NOAA satellites in the POES program) and DMSP satellites were brought about for several reasons. Many of these were technology driven, taking advantage of a technology that had become more feasible and less costly than in previous years. These improvements were primarily made to increase operational life or to increase performance. Other enhancements are experimental in nature, some driven by the development of new models and analysis tools, and some to explore new technologies, leading to quality products that have come to be invaluable to environmental forecasting today. POES evolution in capability is depicted in Figure 1-1.

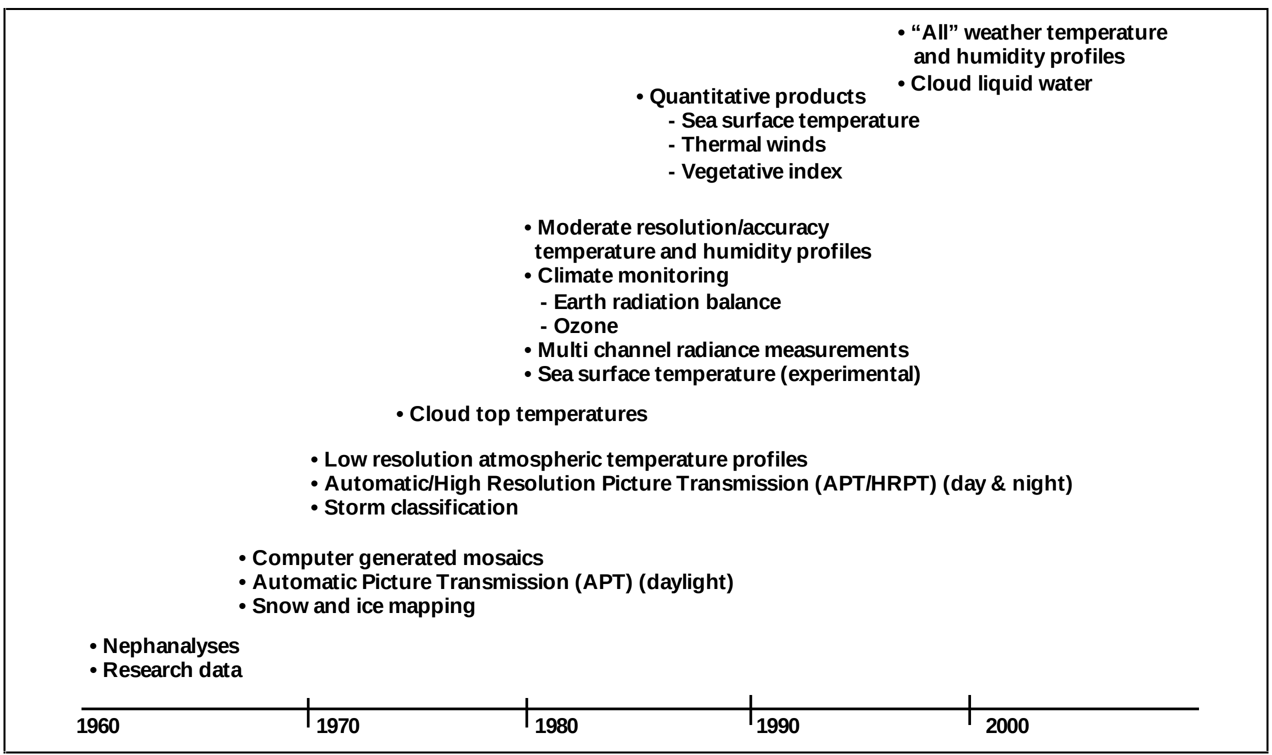

Figure 1-1. Significant POES Evolutionary Products[4]

[4] "Evolutionary Nature of the TIROS/ESSA/NOAA Polar-Orbiting Satellite Program", Draft, 11/9/95, A. Schwalb, MITRE Corporation

Major system enhancements for DMSP are shown in Figure 1-2. These enhancements, along with those of NOAA, have contributed to the following impacts over that time:

- From DMSP Southeast Asia Site 6 Report November 1966, "During November, the tactical use of satellite (DMSP) data aided 877 mission forecasts; 852 (97.2 percent) of the forecasts were later verified as being correct."[5]
- Studies done by two companies, Exxon (1975) and Crowley (1983) have shown large fuel savings by Optimum Track Ship Routing (OTSR). Commercial savings for these companies exceeded $10 million per year. Fleet Numerical Meteorology and Oceanography Center-generated global OTSR information relies heavily on DMSP and NOAA data and leads to $100s of millions in fuel savings to the U. S. Fleet.[6]
- A NASA Lewis Research Center Study in 1981 found cost savings for a major U. S. overseas airline through minimum fuel routing, equating to $40 million per year in 1993 dollars. The NOAA and DMSP data contribute to the minimum fuel flight planning by civil and military agencies.[7]
- Utilization of DMSP satellite data has significantly reduced aircraft (Coast Guard) ice patrol cost. A NOAA study (mid-1980's) showed a $5 million per year savings.[8]
- During Desert Storm, the key initial strikes during the first two days of the air war were supported by DMSP-derived Electro-Optical Tactical Decision Aids forecasts with one hundred percent accuracy.[9]
- The National Weather Service uses data from NOAA's polar orbiter in its computer-driven forecast systems. The data are especially important for producing medium-range (3- to 10-day) weather forecasts.[10]
- For the DoD, the primary source of satellite data for forecast models is DMSP, however, POES data is used for soundings (TIROS Operational Vertical Sounder).[11]

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[5] "Defense Meteorological Satellite Program - Three Decades of Cost Effective Military Support", Martin Marietta Astro Space
[6] Ibid.
[7] Ibid.
[8] Ibid.
[9] Ibid.
[10] "Weather Satellites - Systems, Data and Environmental Applications, American Meteorological Society, Boston, 1990
[11] "Functional Description: Air Force Global Weather Central Meteorological Models Workcenter (AFGWC/SYSM)", L. M. Englehart et al., Aerospace Corporation, 1993.

- NOAA, the Air Force, and the Coast Guard participate in a search and rescue program using readings from NOAA's polar orbiters on the location of downed planes and ships in distress. The search and rescue satellite payload relays distress signals from land travelers as well from ships and aircraft.[12]
- Both DoD and NOAA use satellite data from polar orbiters to generate global maps of snow cover (daily for DoD and weekly for the National Environmental Satellite, Data and Information Service (NESDIS)), which have impacts on agriculture (e.g., water storage levels) and river forecasts (e.g., flood forecasts), which in turn have large impacts (lives, dollars) on civil and military activities.[13]
- POES data is used by the National Weather Service (NWS) to analyze and forecast lake ice on the Great Lakes, affecting millions of dollars in shipping.[14]

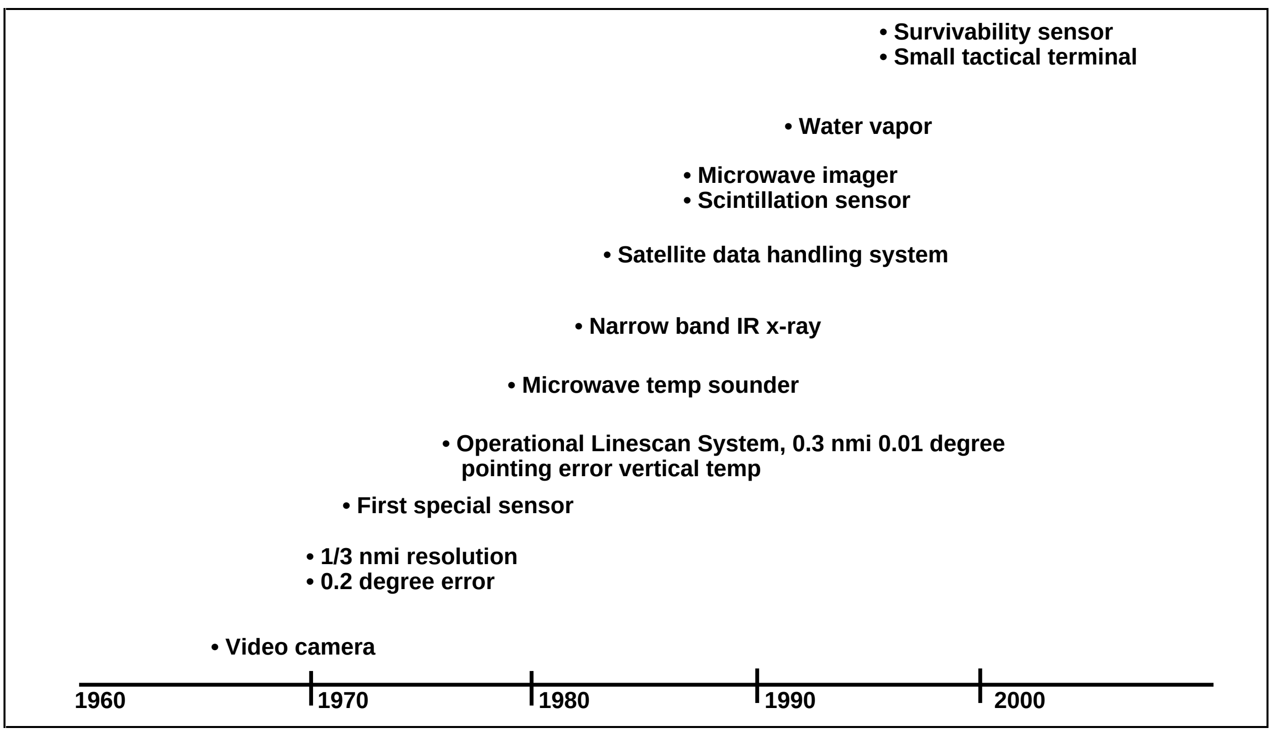

Figure 1-2. Major System Enhancements - DMSP[15]

[12] "Weather Satellites - Systems, Data and Environmental Applications, American Meteorological Society, Boston, 1990
[13] Ibid.
[14] Ibid.
[15] "DMSP Evolution", Briefing Charts, the Aerospace Corporation

1.1.2 Operational and Economic Shortfalls of DMSP and POES

The operational benefits of DMSP and POES data over the past 30 years steadily increased over time as improvements to the satellites were implemented. In order to continue this kind of demonstrated growth of benefits into the next century, changes must be made to the next generation satellites (i.e., NPOESS) to accommodate users'[16] known and projected changing needs. Among the most significant of these are:

- Improve measurement accuracies, resolution, and coverage. These shortcomings result in a lack of contiguous data near the equator which limits its usefulness, and increases the period of time it takes for the satellite to provide global refresh of data.[17] In addition, improved accuracies and more precise resolutions are required to keep up with input requirements to improved forecasting tools.
- Increase refresh rates to monitor rapidly changing environmental conditions. Given the perishability of environmental data, the refresh inadequacies present a severe limitation to "nowcasting" of significant weather events affecting limited geographic areas. With the current DMSP and POES systems, the data refresh rate ranges from 15 to 415 minutes.[18] Although the refresh rate ranges are due to the combination of a number of effects, the main cause of long refresh is the lack of contiguous coverage at the equator coupled with the fact that not all sensors fly on all platforms (e.g., SSM/I, which flies only on DMSP). A lesser overall factor is "unequal spacing," of the satellites which impacts maximum refresh more than average refresh (see Section 4.3.2). This can result in DoD theater components providing customer support based upon data that are hours old. Local phenomena may develop and dissipate prior to receipt of the sensed data at the Centrals.[19]

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[16] For NOAA, users include National Weather Service, National Ocean Service, National Marine Fisheries Service, Office of Oceanic and Atmospheric Research and all related line organizations. For DoD, users are from all services and include the 50th Weather Squadron, Air Force Global Weather Central, Navy Fleet Numerical Meteorological Oceanography Center, and Naval Oceanographic Office and all related line organizations. NASA is also a user of the NPOESS system. Note that those organizations that use data or products from these organizations are also considered users.
[17] NPOESS IORD-I, Section 3.1, December 1995
[18] Ibid.
[19] Ibid.

- Broad area enhancements for more comprehensive and complete measurement of a host of parameters that require long-term, operational data collection for guaranteed day-to-day and long-term data applications. With more accurate information, positive steps can be initiated to prevent problems that can be controlled.   In particular, these are meteorological, environmental, oceanographic, and climatic missions which require increases both to the quality and quantity of data collected for many atmospheric, cloud, earth radiation budget, land, ocean/water, and space environment parameters. Specialized sensors/capabilities such as ocean color, altimetry, earth radiation budget, and solar irradiance sensors specifically address these requirements/missions. In addition several other parameters (pre-planned product improvements (P^3I)) were also identified as capabilities that are important enhancements that hold important implications to future support of critical DoD and DOC mission areas.

The details of these user requirements are documented in IORD-I. Both Section 4.2.2 and Appendix G of this document elaborate on the mission impacts of not achieving some of these requirements.

For over 20 years the U. S. has operated two separate, but complimentary, polar-orbiting environmental satellite systems: one civilian (POES) and one military (DMSP).   In recent years the requirements of the two systems have been converging. Thus, to reduce the costs of acquiring and operating polar-orbiting satellites, a White House Decision to integrate the two polar weather satellite programs (DMSP and POES) into a single converged system was announced in May 1994. This decision, as part of a National Performance Review recommendation, is expected to save the U. S. Government up to an estimated $300 million in fiscal year (FY) 96 to FY99 dollars with additional savings expected after FY99. Savings will be largely determined by comparing the costs of the converged weather satellite program to the planned costs of the DMSP Block 6 and NOAA O,P,Q,R series of follow-on satellites. The performance of the converged system will be based on converged user requirements as defined in the Integrated Operational Requirements Document (IORD)-I.

1.2 THREAT

Likely future threats against an NPOESS-like system fall into three broad categories. The first is electronic warfare designed to disrupt user communication links and/or satellite control. The second is the physical threat to NPOESS users and control segments from sabotage, terrorist attacks etc. The third threat is a direct antisatellite attack against the space segment, either high altitude nuclear detonations or laser. Further information on these threats (including references) is contained in NPOESS IORD-I, Section 2 and in the classified System Threat Analysis Report (STAR).[20]

1.3 ENVIRONMENT

The operational environment of the NPOESS satellites and the orbital dynamics are similar to the existing POES and DMSP satellites. Thus, the design of the satellite for its natural environment, including radiation, should not be a high risk item since proven satellite design techniques will be utilized. Similarly, the NPOESS ground segment will utilize existing command, control, communications, and processing sites which have already demonstrated their capability to operate in the natural local environment.

1.4 GUIDANCE AND CONSTRAINTS

The following guidance regarding proposed NPOESS architectures establishes the constraints for this analysis. The constraints fall into three categories as shown below: operational requirements, implementation, and cost. Relaxation of several of these constraints are explored in trade-off analyses (Section 4.3). Specific constraints relevant to the analysis of cost and operational benefits are discussed under Sections 4.1.1 and 4.1.2 respectively.

[20] NPOESS IORD-I, Section 2.0, December 1995

Operational Requirements

- "Approved operational requirements will define the converged system baseline..."[21]
- The "IORD will be the sole operational requirements source from which tri-agency cost and technology assessments, specifications development, and related acquisition activities will be conducted."[22]
- "Assured access to operational environmental data will be provided to meet civil and national security requirements and international obligations."[23]

Implementation

- The optimum converged constellation is three satellites in sun-synchronous orbits with even temporal spacing.[24] (IPO considered only polar-orbiting solutions)

Cost

- DMSP Block 6/NOAA O,P,Q,R will be the cost savings baseline.[25]
- The reference DMSP Block 6/NOAA O,P,Q,R baseline estimate is $9.1 billion (B) then-year (TY) dollars.[26]
- Cost savings targets for three system alternatives are $0.0, $1.3B, and $2.0B (TY dollars), measured against the combined costs of DMSP Block 6 and NOAA O,P,Q,R.[27]

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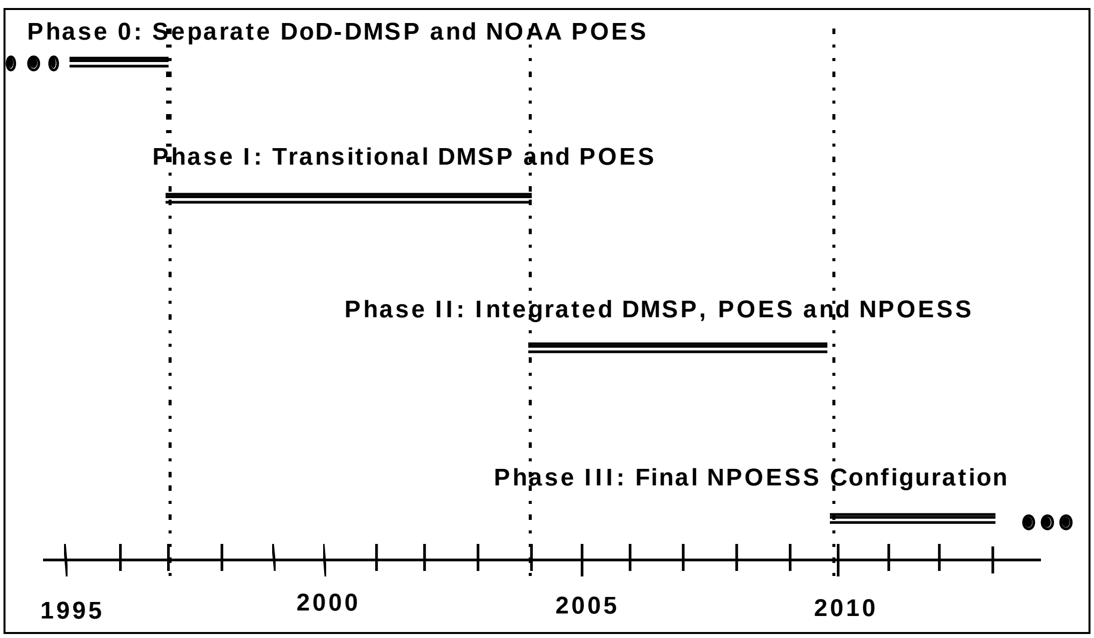
[21] Presidential Decision Directive/National Science and Technology Council (PDD/NSTC-2), Section III-a-2, 5 May 1994
[22] Tri-agency MOA for NPOESS, Appendix 2, 26 May 1995
[23] Presidential Decision Directive/National Science and Technology Council (PDD/NSTC-2), Section II, 5 May 1994
[24] Implementation Plan for a Converged Polar-orbiting Environmental Satellite System, Section III, Orbit Timing, page 17, 2 May 1994, Office of Science and Technology Policy
[25] Implementation Plan for a Converged Polar-orbiting Environmental Satellite System, Executive Summary, Budgeting, page v, 2 May 1994, Office of Science and Technology Policy
[26] "Reconciliation of NOAA O,P,Q,R and DMSP Block 6 Life Cycle Cost Estimates", 19 April 1995
[27] Guidance for Phase 0 COBRA for The NPOESS Program, Analysis Structure, page 1, 11 October 1995

1.5 OPERATIONAL CONCEPT

The NPOESS Command, Control, and Communications (C^3) Concept of Operations will cover four phases of polar satellite operations between now and approximately 2010, at which time there will be a full up NPOESS constellation consisting of two U. S. and one Meteorological Operational (METOP) satellite. These phases cover not only the period of operation of the new NPOESS (circa 2004+), but also transitional periods, commencing with the transfer of operations of the DoD DMSP and NOAA POES to the IPO (circa 1997), and the flights of the METOP satellites by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) commencing around the year 2000. Figure 1-3 shows the timeline[28] for each phase. Because of uncertainties associated with exact dates of each phase, these dates are for reference only. A summary description of each phase is provided in Appendix B. For costing purposes, the COBRA considers Phase III to start at Initial Operational Capability (IOC) (two U. S. satellites on orbit) and to continue for 10 years (through 2018).



Note: Dates are notional

Figure 1-3. Phases of NPOESS Convergence Operations

1.6 SCENARIO

It is recognized that the Defense Planning Guidance provides information on specific scenarios and missions that are to be used in cost and operational effectiveness analyses (COEAs) and other similar studies. Due to the wide-ranging set of missions and operations in which weather information is critical, it would be impossible to generate assessments for every mission impacted by the COBRA alternatives. Instead, representative missions and operational scenarios, as selected by the users, were addressed in the operational benefit analysis as they were relevant to the environmental data record (EDR) differences between the COBRA alternatives. These missions/scenarios were mapped to one of five functional categories for summary purposes. Specific scenarios and missions will be discussed in Section 4, Analysis of Alternatives, and Appendix G, as appropriate.

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[28] "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System", Section III, Ground Segment, page 21, 2 May 1994, Office of Science and Technology Policy

SECTION 2

REQUIREMENTS OVERVIEW

The COBRA requirements overview discusses the major aspects of the current requirements and an assessment of the current capabilities.

2.1 REQUIREMENTS

The NPOESS program will be required to provide a remote sensing capability to acquire, receive at ground terminals, and disseminate to processing centers, global and regional environmental imagery and specialized meteorological, climatic, terrestrial, oceanographic, solar-geophysical and other data in support of DOC/NOAA mission requirements, and DoD peacetime and wartime missions. NPOESS has four segments: 1) space, 2) launch support, 3) C^3 , and 4) interface data processor (IDP). A discussion of the requirements for each of the segments is provided in the NPOESS IORD-I Section 1.3. The “integration” of these four segments into the NPOESS configuration determines the NPOESS ability to satisfy the system level requirements and performance requirements (i.e., EDRs to be delivered) set forth in IORD-I Sections 4.1.5 and 4.1.6, respectively.

The Joint Agency Requirements Group (JARG) was responsible for developing IORD-I. The Systems Engineering staff at the Integrated Program Office (IPO) conducted trade-off analyses to support the JARG. These efforts are discussed under Section 3.1.

2.2 CURRENT AND PLANNED CAPABILITIES: DMSP AND POES

For reference purposes, the ability of present and planned systems to satisfy the current IORD-I requirements was assessed by the IPO and is shown in Appendix C. Table C-1 lists the sensors for both the DMSP Block 5D3 and NOAA K-N’ plus METOP. Table C-2 shows how these systems, both individually as well as a “combined” system, would perform against the NPOESS IORD-I threshold level requirements. Tables C-3 and C-4 provide similar information for the planned DMSP Block 6 and NOAA O,P,Q,R systems. Performance assessments (tables C-2 and C-4) are presented in the form of a “stop-light” chart (assessments using colors ranging from “Red” to “Blue”) against the IORD-I EDRs and system level requirements.

SECTION 3

ALTERNATIVE DEFINITION

The COBRA alternatives were defined during a six month period coincident with the JARG process. This section discusses the methodology used to develop these alternatives and a detailed description of each.

3.1 ALTERNATIVE DEFINITION PROCESS/METHODOLOGY

The objective for Phase 0 COBRA alternative definition process was to define systems that would satisfy as many of the December 1995 NPOESS IORD-I requirements (system-level, EDRs) as possible within the cost constraints imposed by the COBRA guidance. Per COBRA guidance and the NPOESS implementation plan, alternative definition was a user-driven process. To ensure consistency in the development of the COBRA alternatives, a series of integrated engineering tools linked together with data interfaces were used to explore the cost and technical performance of various alternatives. This process will be discussed in Section 4.1.1, Life Cycle Cost Analysis Methodology and Data.

The technical aspects of the alternative definition process, as shown in Figure 3-1, were based on a series of summary-level cost-performance trade-off analyses conducted by the IPO Systems Engineering organization. In early 1995, two Phase 0 contractors were tasked by the IPO to conduct feasibility studies to determine the level of capability and "NPOESS system" that could be developed to meet user requirements. The COBRA trade-off analyses considered these Phase 0 studies as well as internal IPO and other Government studies. The technical aspects of these architectures were designed for satisfaction of IORD-I requirements and were tailored through a series of iterations over several months through interaction (review/discussion/redirection) with the users, as represented by the NPOESS JARG. Many alternatives were generated during the conduct of these trade-off analyses, focusing on different sets of EDRs and other user requirements, to arrive at a starting point for defining the most effective cost-constrained alternatives for the COBRA. These analyses also provided cost sensitivity data to the users to aid them in refining requirements for IORD-I. During this process, users/IPO agreed that the IORD-I performance was driven primarily by the space segment. Therefore, the IPO adopted a conventional architecture for the C^3 and ground processing segments, sized to accommodate each space segment configuration (e.g., Domestic Satellite (DOMSAT) communications relays versus Tactical Data Relay Satellite System (TDRSS)). Other options will be evaluated by the prime contractors in Phase I of the NPOESS program. The C^3 and processing segments are described in Appendix D, Section D1.

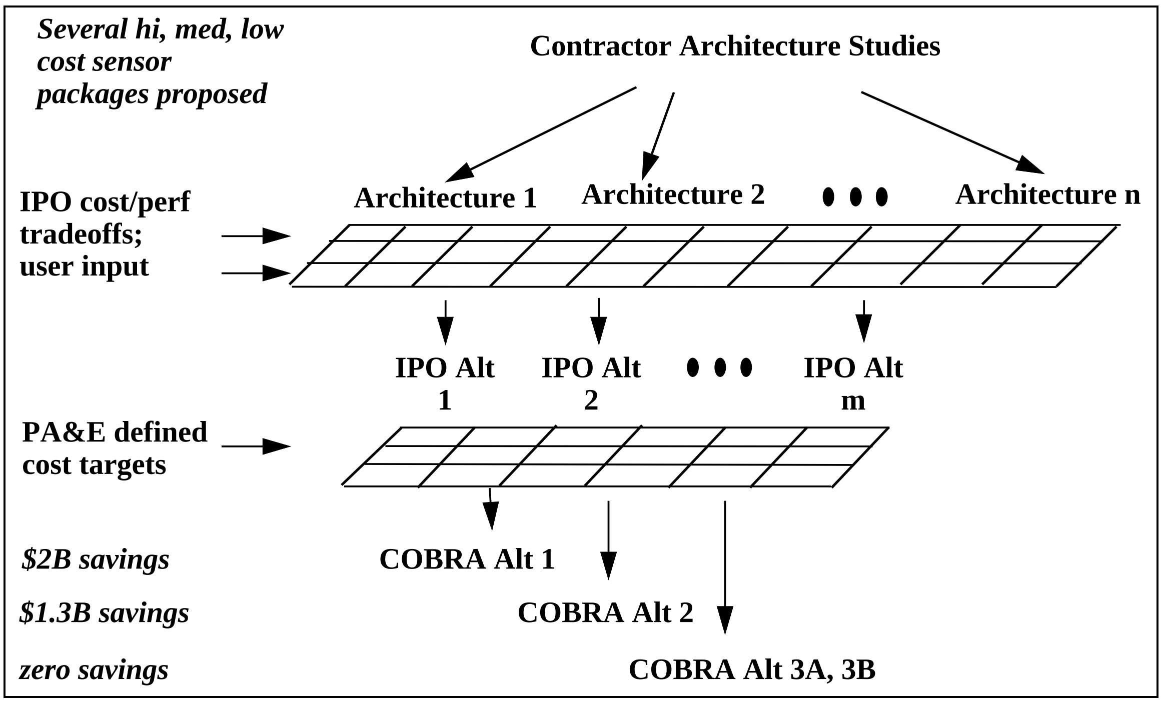


Figure 3-1. Alternative Definition Process

Final results defined a system (Alternative 2) that satisfied the IORD-I threshold level requirements (all system-level requirements and 61 of 70 EDRs) within the specified cost constraint (i.e., $1.3B life cycle cost (LCC) savings from the combined follow-on DMSP and POES program costs in then-year dollars, as directed in the Vice President's National Performance Review (NPR)). The nine EDRs that were not satisfied by Alternative 2 are specially categorized as P^3I EDRs. They include those elements of the NPOESS mission needs identified in the Phase 0 contractor studies as having potentially restrictive technical or programmatic uncertainties.[29] A subset of IORD-I requirements were then analyzed, guided by user priorities, to determine a minimum cost alternative to meet the most stringent cost target (i.e., \$2.0B LCC savings per COBRA guidance); this system (Alternative 1) meets 50 of 70 EDRs at the threshold level plus all system-level requirements, except for "system survivability" (non-key). In order to satisfy EDRs, in addition to the 61 satisfied by Alternative 2, the remaining IORD-I requirements were also analyzed to determine which EDRs could be "added" to meet the final COBRA cost target (i.e., \$0.0B LCC savings). Two systems were defined and are presented as high cost alternatives (Alternatives 3A and 3B).

Due to the ability to satisfy the majority of requirements within the defined cost constraints, it was not necessary to explore alternatives dealing with satisfaction of a lesser set of requirements and/or a relaxation of the guidance/constraints set forth in Section 1.4. However, results of the architecture trade-off studies (as shown in Figure 3-1) conducted by the IPO in arriving at Alternative 2, showed that some system elements common to all alternatives constituted significant cost elements. Since these elements did not change across the final COBRA alternatives, they fell outside the operational benefit analysis process. In order to provide the "decision-makers" with supplementary information in the event additional cost constraints are imposed on the NPOESS program, a "cost sensitivity" analysis was performed on selected elements of the COBRA alternatives. These analyses, discussed in Section 4.3 (Trade-off Analyses and Other Studies) of this report, indicated that additional cost avoidance could be achieved at the expense of IORD-I requirements satisfaction.

3.2. DESCRIPTION OF ALTERNATIVES

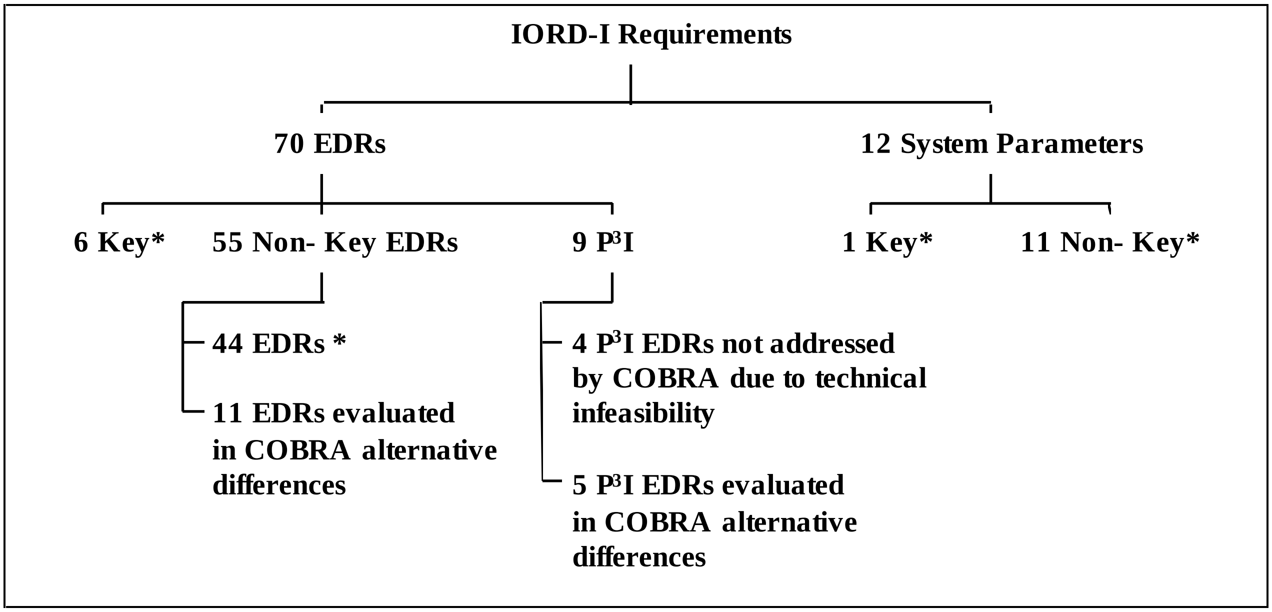
The process of defining the COBRA alternatives revealed the main cost and performance/ requirements driver, once system-level requirements were met, was the space segment, specifically the payload definition. During iterations with the user, performance levels better than threshold were sometimes retained while in other instances configurations were explored that reduced performance below threshold in order to add capabilities elsewhere. The COBRA

[29] NPOESS IORD-I, December 1995

alternatives differ with respect to the payload, the selection of sensors and instruments that provide the raw environmental data used to develop EDRs. Thus, the COBRA alternatives differ only with respect to EDR satisfaction, except for Alternative 1 which also lacks "system survivability".

Figure 3-2 depicts the hierarchy of IORD-I requirements. Of the 82 requirements described in IORD-I, 12 are system parameters (e.g., availability) and 70 are EDRs. The EDRs are the primary drivers of the space segment. Of the 12 system parameters, only one is a key parameter (data access). Of the 70 EDRs, six are key EDRs (with one or more key attributes (e.g., measurement accuracy)), 55 are non-key EDRs and nine are P^3I EDRs. Key parameters are those for which the Milestone Decision Authority "would require a reevaluation of alternative concepts or design approaches, and may cause program termination if the thresholds are not met. The key performance parameters are those essential for successful mission accomplishment."[30] All key parameters are satisfied to threshold, or exceeded, for all of the COBRA alternative concepts. Non-key parameters are also critical to the success of multiple NPOESS users' missions. Therefore, for the purposes of this COBRA, all non-key EDRs can potentially cause critical mission failure if unmet.

[30] Requirements Generation System Policies and Procedures, Memorandum of Policy No. 77, 17 September 1992, Chairman of the Joint Chiefs of Staff



* These requirements are satisfied to (or exceed) IORD-I thresholds for all the COBRA alternatives since they were determined to be affordable under all COBRA cost constraints (except for Alternative 1 which lacks "system survivability"). Therefore, these requirements are not evaluated in the COBRA.

Figure 3-2. Structure of IORD-I Requirements

Table 3-1 presents the payload sensors for each alternative. Table 3-2 presents the 50 EDRs that are commonly delivered by all alternatives to threshold levels stated in IORD-I. Additional EDRs delivered by each COBRA alternative are presented in Table 3-3 where a "+" indicates which EDRs are satisfied to IORD-I threshold levels. The EDR differences between the alternatives shown in Table 3-3 are the focus of the operational benefit analysis (life cycle cost analysis is completed for the entire alternative) and represent three main measurement areas: ocean/water, earth radiation budget, and potential P^3I. (The issue of system survivability will be discussed later in this section and in Section 4.) The priority for deleting or adding EDRs (from/to Alternative 2) in Alternatives 1, 3A, and 3B was established by the JARG. Note that the four P^3I EDRs not considered by the COBRA are: bathymetry, bioluminescence, optical backgrounds, and salinity, due to their extreme technological uncertainty and/or complexity.

Table 3-1. Alternative Characterization - Payload and Implementation

Notional COBRA Sensors	ALT 1	ALT 2	ALT 3A	ALT 3B
Visible (VIS)/Infrared (IR) Imager Radiometer	a, b, c			
VIS/IR Imager Radiometer w/Ocean Color		a, b, c	a, b, c	a, b, c
Low Light VIS Imager	a, b, c	a, b, c	a, b, c	a, b, c
Cross-track IR Sounder	b	b	b	b
Cross-track Microwave (MW) Temperature Sounder	b, c	b, c	b, c	b, c
Conical MW Imager/Sounder	a, b, c	a, b, c	a, b, c	a, b, c
Ozone Monitor	b	b	b	d
Enhanced Ozone Profiler				d
Data Collection System	a, b, c	a, b, c	a, b, c	a, b, c
Search and Rescue	a, c	a, c	a, c	a, c
Space Environmental Suite (SES)	a, b, c	a, b, c	a, b, c	a, b, c
Earth Radiation Budget Sensor		b	b	b
Solar Irradiance Sensor		a	a	a
Radar Altimeter		a	a	a
Wind Lidar			d	
CH_4 (Methane)/CO (Carbon Monoxide) Monitor				d
CO_2 (Carbon Dioxide) Monitor				d

Based on notional system for costing purposes

a, b, c and d indicate which spacecraft a particular instrument is flying on, where a = 0530 NPOESS orbit, b = 1330 NPOESS orbit, c = 0930 EUMETSAT orbit, d = free-flier

Table 3-2. EDRs (50) Satisfied by All Alternatives to IORD-I Levels

IORD Ref.	EDR	IORD Ref.	EDR
4.1.6.1.1	Vertical Moisture Profile*	4.1.6.6.3	Ice Surface Temperature
4.1.6.1.2	Vertical Temperature Profile*	4.1.6.7.7	In-situ Ion Drift Velocity
4.1.6.1.3	Imagery*	4.1.6.7.8	In-situ Plasma Density
4.1.6.1.4	Sea Surface Temperature*	4.1.6.7.9	In-situ Plasma Fluctuations
4.1.6.1.5	Sea Surface Winds*	4.1.6.7.10	In-situ Plasma Temperature
4.1.6.1.6	Soil Moisture*	4.1.6.7.11	Ionospheric Scintillation
4.1.6.2.1	Aerosol Optical Thickness	4.1.6.5.1	Land Surface Temperature
4.1.6.2.2	Aerosol Particle Size	4.1.6.6.5	Net Heat Flux
4.1.6.4.1	Albedo (Surface)	4.1.6.7.12	Neutral Density Profiles/ Neutral Atmospheric Specification
4.1.6.7.1	Auroral Boundary	4.1.6.5.2	Normalized Difference Vegetation Index
4.1.6.7.2	Total Auroral Energy Deposition	4.1.6.2.3	Ozone Total Column/Profile
4.1.6.7.3	Auroral Imagery	4.1.6.2.4	Precipitable Water
4.1.6.3.1	Cloud Base Height	4.1.6.2.5	Precipitation (Type/Rate)
4.1.6.3.2	Cloud Cover/Layers	4.1.6.2.6	Pressure (Surface/Profile)
4.1.6.3.3	Cloud Effective Particle Size	4.1.6.7.13	Radiation Belt and Low Energy Solar Particles
4.1.6.3.4	Cloud Ice Water Path	4.1.6.6.8	Sea Ice Age and Sea Ice Edge Motion
4.1.6.3.5	Cloud Liquid Water	4.1.6.5.3	Snow Cover/Depth
4.1.6.3.6	Cloud Optical Depth/ Transmittance	4.1.6.7.14	Solar and Galactic Cosmic Ray Particles
4.1.6.3.7	Cloud Top Height	4.1.6.7.15	Solar Extreme Ultra Violet (EUV) Flux
4.1.6.3.8	Cloud Top Pressure	4.1.6.7.16	Supra-thermal through Auroral Energy Particles
4.1.6.3.9	Cloud Top Temperature	4.1.6.6.10	Surface Wind Stress
4.1.6.7.4	Electric Field	4.1.6.2.7	Suspended Matter
4.1.6.7.5	Electron Density Profiles/ Ionospheric Specification	4.1.6.2.8	Total Water Content
4.1.6.6.2	Freshwater Ice Edge Motion	4.1.6.7.17	Upper Atmospheric Airglow
4.1.6.7.6	Geomagnetic Field	4.1.6.5.4	Vegetation Index/Surface Type

* designate EDRs which contain attributes which have “key” performance parameters

Table 3-3. Additional EDRs Satisfied by the COBRA Alternatives

EDR Differences from ALT 1	ALT 1	ALT 2	ALT 3A	ALT 3B
Ocean/Water				
Currents (near shore/surface)		+	+	+
Littoral Sediment Transport		+	+	+
Ocean Color/Chlorophyll		+	+	+
Turbidity		+	+	+
Ocean Wave Characteristics		+	+	+
Sea Surface Height/Topography		+	+	+
Earth Radiation Budget				
Downward Longwave Radiation (Surface)		+	+	+
Insolation		+	+	+
Total Longwave Radiation (Top of Atmosphere (TOA))		+	+	+
Net Shortwave Radiation (TOA)		+	+	+
Solar Irradiance		+	+	+
P^3I				
Tropospheric Winds			+	
CH_4 (Methane) Column				+
CO (Carbon Monoxide) Column				+
CO_2 (Carbon Dioxide) Column				+
Ozone Profile - High Resolution				+

+ = satisfied to IORD-I threshold levels
P^3I = pre-planned product improvements

Appendix D provides detailed information on all segments of the COBRA alternatives. For the space segment, the focus of the COBRA alternative differences, instrument descriptions are provided. For the remaining segments, a general description of each is provided. The alternative differences in these segments are minimal and are in the “sizing” of the segments due to the payload differences. A more detailed description of all segments is provided in the Cost Analysis Requirements Description (CARD) which reflects COBRA Alternative 2. The performance of each alternative against the IORD-I threshold level requirements is also presented in Appendix D. Cost differences will be shown in Section 4.2.1 of this report.

It is important to note that the COBRA alternative concepts presented are notional, depicting systems which could be built for the indicated costs. The notional sensors were chosen for the COBRA alternatives based on their ability to satisfy EDRs against the threshold performance levels specified in IORD-I. Both the notional instruments and architectures were also used for cost estimating purposes. Contractor-developed systems proposed for Phase II/III may, or may not, resemble these systems.

Additional information on NPOESS EDRs is provided in Appendix E. Appendix E briefly defines each EDR and discusses, within several general usage categories, how the EDR is used. It also maps specific instruments to the EDRs which they support and defines the required data collection time as appropriate. A list of references for this data is provided at the end of this appendix.

The next section provides an overview of the space/payload implementation scheme that is generally applicable to all COBRA alternatives. The remaining sections give a summary description of each alternative that captures the information from the previous three tables.

3.2.1 General NPOESS Space/Payload Implementation

It is anticipated that NPOESS will collect operational data using satellites flying in sun-synchronous near-polar orbits with the following nominal nodal crossing times - 0530 ascending, 0930 descending, and 1330 ascending - designated “a”, “c”, and “b”, respectively in this report. Satellites in orbits “a” and “b” are considered U. S. assets and will be developed, acquired, deployed, and operated by the U. S. Government. Satellites in orbit “c” are European METOP satellites and will be developed, acquired, deployed, and operated by EUMETSAT, the European meteorological satellite agency. Operational satellites are those satellites which continue to be operated to fulfill a substantial part of the mission. To the extent practical, residual satellites may be maintained on orbit on a non-interference basis for supplemental collection capability, operational back-up, test and evaluation, etc. Residual satellites are those satellites which continue to be maintained on orbit, but from which only limited amounts of useful data are obtained. All NPOESS and METOP satellites will be launched on an as-needed-basis.

Each satellite will carry a variety of sensors to provide both military and civil environmental data (see previous Table 3-1). Pending an international agreement, payloads may be exchanged between the U. S. Government and EUMETSAT. This arrangement is called the Joint Polar-orbiting Satellite System (JPS). Under this arrangement, some U. S. Government payloads will fly on EUMETSAT satellites (designated METOP). In this way, the U. S. and European requirements will be met jointly by NPOESS satellites and METOP satellites beginning with METOP-3. A similar arrangement, called the Initial JPS (IJPS), is currently under negotiation. IJPS shares POES and METOP -1, -2 assets. For the purposes of this COBRA, it is assumed that all of the payloads required to meet NPOESS requirements are U. S. Government instruments. It is further assumed that one of the satellites in the NPOESS constellation will be a METOP satellite, which will carry the necessary U. S. payloads.

The next sections give a summary description of each NPOESS alternative that captures the information from Tables 3-1 to 3-3. Each alternative contains payload instruments for both the U. S. and METOP satellites as discussed above. Note that the characteristics of the non-space segments (launch, C^3, and IDP) vary minimally among the alternatives and are represented by the notional alternative presented in the CARD (also known as COBRA Alternative 2). Any ground architecture trade-offs which are independent of the space segment, yet may be significant cost drivers, are discussed in Section 4.3.

3.2.2 Alternative 1

Alternative 1 achieves the most stringent cost savings goal in that it meets the $2.0B LCC savings target (as compared to the combined cost of the follow-on DMSP and POES programs). It satisfies all system-level requirements, except "system survivability", and "a COBRA core set" of 50 EDRs at the threshold level. It is limited, however, by its inability to provide six ocean/water EDRs due to lack of an altimeter and ocean color channels on the imager, by the inability to provide five earth radiation budget (ERB) EDRs due to lack of an ERB and solar irradiance sensor, and by its inability to provide any P^3I EDRs (see Appendix D for additional details).

3.2.3 Alternative 2

Alternative 2 is considered the IPO baseline or medium cost alternative in that it meets the $1.3B LCC savings target. Alternative 2 satisfies all system-level requirements, including "system survivability", and satisfies all non-P^3I EDRs at the threshold level by adding the altimeter, ocean color channels on the imager, and the ERB and solar irradiance sensors. As with Alternative 1, this alternative is limited by its inability to provide any P^3I EDRs.

3.2.4 Alternative 3A

Alternative 3A is considered to be a high cost/advanced capability alternative since its estimated cost approximates the total amount of financial resources originally planned and programmed for the follow-on DMSP and POES programs. This alternative satisfies all system-level requirements and satisfies all non-P^3I EDRs plus the P^3I tropospheric winds requirement by inclusion of a wind lidar. It is limited by its inability to provide the remaining P^3I EDRs.

3.2.5 Alternative 3B

Alternative 3B also is considered to be a high cost/advanced capability alternative since its estimated cost approximates the total amount of financial resources originally planned and programmed for the follow-on DMSP and POES programs. This alternative satisfies all system-level requirements and satisfies all non- P^3I EDRs plus the enhanced ozone and trace gas P^3I requirements by inclusion of an enhanced ozone sensor, a carbon monoxide (CO)/methane (CH_4) monitor and a carbon dioxide (CO_2) monitor. It is limited by its inability to provide the remaining P^3I EDRs, including the tropospheric wind P^3I EDR.

SECTION 4
ANALYSIS OF ALTERNATIVES

The primary analyses conducted for this COBRA are discussed in this section. Methodology and data, COBRA results, and trade-off analyses conducted as part of the process in developing the alternatives are described.

4.1 METHODOLOGY AND DATA

Methodology and data for both the life cycle cost analyses and the operational benefit analysis conducted for the COBRA are discussed in this section.

4.1.1. Life Cycle Cost Analysis Methodology and Data

Estimates for the alternatives were generated by a variety of cost models used in a combined systems engineering/cost analysis process and cross-checked, when possible, against the Phase-0 contractor's estimates and actual costs of hardware developed for similar environmental satellites. Costs generated from the systems engineering/cost analysis implementation were produced in the IPO Work Breakdown Structure (WBS) format. Specific cost estimation ground rules and assumptions were established as follows:

- Life cycle costs begin with the start of Phase 0 and end in 2018, 10 years after IOC (2 U. S. satellites on orbit).
- Only costs to be funded out of NPOESS budget lines are included in the COBRA estimates. The Program Office Estimate considers the additional costs to the U. S. Government that will be funded out of non-NPOESS budget lines.
- Costs were estimated for six (6) space vehicles and two (2) additional payload sets to be provided to EUMETSAT.
- Where instruments provided by NASA are not designed to meet the required NPOESS Mean Mission Duration (MMD), MMD life extension costs were estimated.
- All spacecraft and payload estimates include contingencies for technical risk.

- Spacecraft and payload are new developments. Heritage, if any, was factored into the design margins (e.g., mass, power, volume).
- Integrated logistics support costs are included.

The following section discusses the overall process and the methodology used to develop the cost estimates for each of the four NPOESS segments.

4.1.1.1 Systems Engineering/Cost Analysis Process

The IPO used a combined systems engineering/cost analysis process for evaluating point designs, which took into consideration the requirements issues, contractor design concepts and other Government studies to develop the COBRA alternatives (low, medium and high cost concepts). The process was implemented with a set of integrated engineering tools/cost models linked together with data interfaces. This set of tools also facilitates evaluation of technical trades to understand relative cost impacts of various alternative architectures. Figure 4-1, presents an overall picture of how architecture information is used to complete the alternative cost estimates.

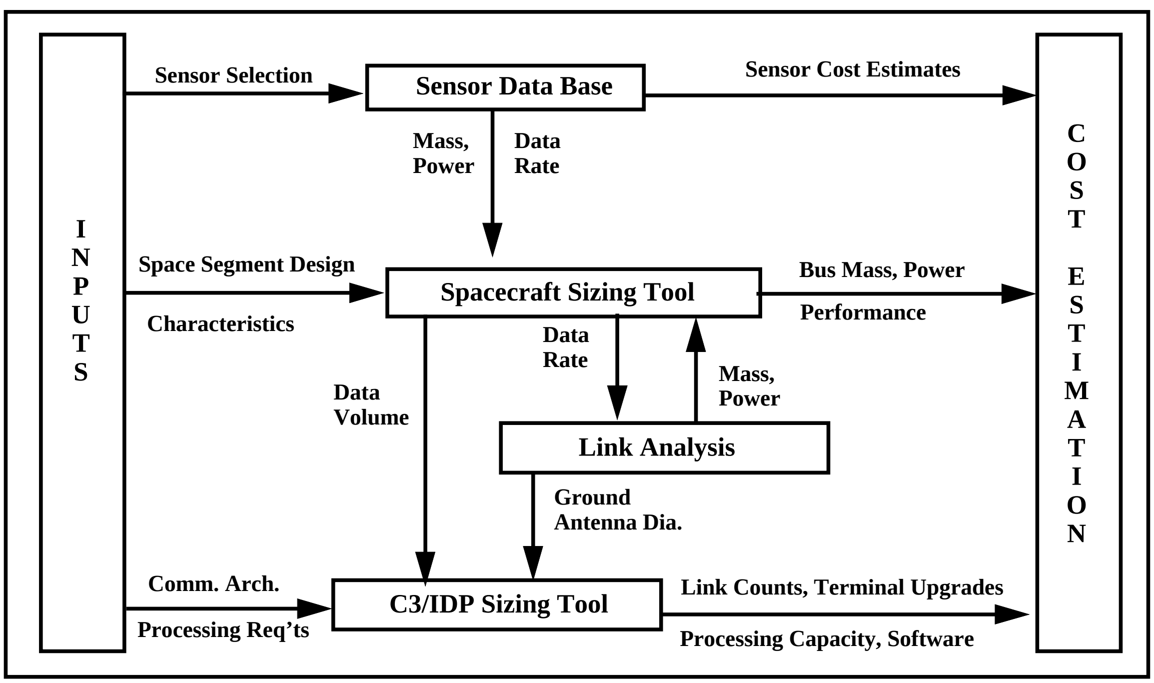


Figure 4-1. Systems Engineering/Cost Analysis Flow[31]

[31] NASEM Introductory Briefing, 21 June 1995, R. Gleiter, A. Dawdy, The Aerospace Corporation

Space Segment Cost Methodology. The space segment includes the costs, i.e., hardware, systems engineering/program management (SE/PM), and integration, assembly and test (IA&T) for the spacecraft bus and payload sensors plus the space vehicle IA&T. The primary cost estimating tool for the spacecraft bus was the Spacecraft Subsystems Cost Model (SSCM) developed by the NASA Goddard Resource Analysis Office (RAO). The latest version of the model is dated July 1991 and includes weight-based nonrecurring and follow-on flight unit cost estimating relationships (CERs) developed from a database of 48 unmanned, earth-orbiting satellite programs. The SSCM was used, since: (1) its database includes 22 environmental applications-type satellites including the Geostationary Operational Environmental Satellite (GOES) 1-3, LANDSAT 1-4, NOAA A through G, and TIROS M-N, and (2) its nonrecurring CERs are based on a protoflight[32] development approach, which is the approach specified in the CARD for the NPOESS spacecraft bus.

The bus subsystem masses used as inputs for the SSCM CERs were developed by the Aerospace Corporation using four different methodologies: existing "catalog" or "off-the-shelf" information (for the attitude determination and control subsystem), analytical relationships (for the propulsion and power subsystem), empirical relationships (for the structure and thermal systems), and detailed off-line simulations (e.g., solar array degradation, three-dimensional solid modeling, orbital degradation, and station-keeping requirements). In addition to these four methods, the results of a communications link analysis were used in determining the spacecraft bus mass size. This analysis considered data impacts (compression, selection), spacecraft impacts (transmitter power, antenna diameter), and ground impacts (antenna diameter, rain, availability, elevation) to compute link margins based on the link closure method. The analysis defined the acceptable limits for data quality, spacecraft power consumption, spacecraft field of views, and the use of existing hardware.

The individual payload sensors were estimated by MITRE using analogies to existing sensors and two NASA Goddard parametric models: Scientific Instrument Cost Model (SICM) and the Multi-Variable Instrument Cost Model (MICM). To the extent possible, both models were

[32] A protoflight unit is one in which the qualification and acceptance test are combined for the first flight unit only.

calibrated to IPO-provided actual costs of similar type instruments prior to their use in estimating the NPOESS sensors. The SICM uses a single variable, mass in pounds, as an input for its nonrecurring and flight unit CERs. MICM has a single CER that estimates the total costs, i.e., design, development, test, and evaluation (DDT&E) plus flight unit, for a prototype development instrument. The inputs for the MICM CER are mass in pounds, average power in watts, data rate in kilobits per second, year of first launch minus 1960, instrument family, and instrument class. The total cost output for MICM was broken out into its DDT&E and flight unit components using the NASA developed factors for each instrument family, i.e., radiometers, active microwave, passive microwave, etc.

Launch Support Segment Cost Methodology. The launch vehicle for NPOESS will be a medium launch vehicle (MLV). For the estimates, actual Delta II program office cost for the Delta II 7920 launch vehicle was used.

Ground Segment Cost Methodology: C^3 and IDP. C^3/IDP elements included in the ground segment are the remote tracking station (RTS)/command data acquisition (CDA) (receive data from spacecraft and provide it "bent pipe" to the Centrals); the Satellite Operations Centers (SOCs) (responsible for spacecraft command and control); the Centrals (data processing, data base maintenance); and, real time terminals.

The C^3 segment cost includes hardware (new, modified), common software, associated costs and operations and maintenance for the primary SOCC in Suitland; common software; and, C^3 integration and test. The IDP segment includes total costs for the centrals, common software, development of EDR algorithms, and IDP integration and test. Not included are costs of existing equipment and facilities.

The ground segment costing used the G-Cost estimating tool, program analogies (database on-line item costs and commercial off-the-shelf information), empirical relationships (scale factors from data bases and DCA), approved software cost estimation models (e.g., SEER™[33],

[33] Galorath Associates, Incorporated Seer Technologies Division

Price-S using lines of code as input (estimated per EDR) and first-order Aerospace CERs. The G-Cost estimating tool is Microsoft Excel-based and contains a database of military ground systems and commercial off-the-shelf (COTS) equipment from Air Force Satellite Control Network (AFSCN), Talon Shield, Milstar, vendor and Aerospace in-house information. It uses parametric estimation to generate costs for the ground station, terminals, connectivity, software, processing facilities and personnel.

4.1.2 Operational Benefit Analysis Methodology and Data

As stated in Section 3.2, only payload differences are addressed among the alternatives, and all alternatives satisfy a core set of requirements including 50 common EDRs. “The COBRA will identify the operational implications of differences in effectiveness among alternative system candidates....”.[34] Based on this guidance, only performance differences among the alternatives were explored in the operational benefit analysis. Operational impacts due to lack of specific EDRs provided by each COBRA alternative were examined.

In a classical operational effectiveness evaluation, models are used to derive numerical results for measures of effectiveness (MOEs). However, given the complexity of weather product generation, and the diversity of product use and users, as shown in Figure 4-2, there does not exist a “single” model that describes the contribution of weather to both civilian and military missions. It is recognized by the COBRA study team that, ideally, one would like to show a direct correlation from the improvements in weather data (EDRs) to the improvement in the output of a decision support tool (DST) (e.g., a weather prediction model) and ultimately to a measurable improvement in mission accomplishment. This type of analysis has not been accomplished in the past by either NOAA or the DoD for the <u>specific comparisons made in the COBRA</u>. In addition, the original deadline for completion of the COBRA analysis was the Fall of 1995 to support the development of IORD-I and the CARD. This necessitated use of only existing studies/data to support the analysis. Therefore, quantitative models were not developed or used to generate the operational benefit analyses for the COBRA.

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[34] Guidance for Phase 0 COBRA for The NPOESS Program, Issues, page 6, 11 October 1995

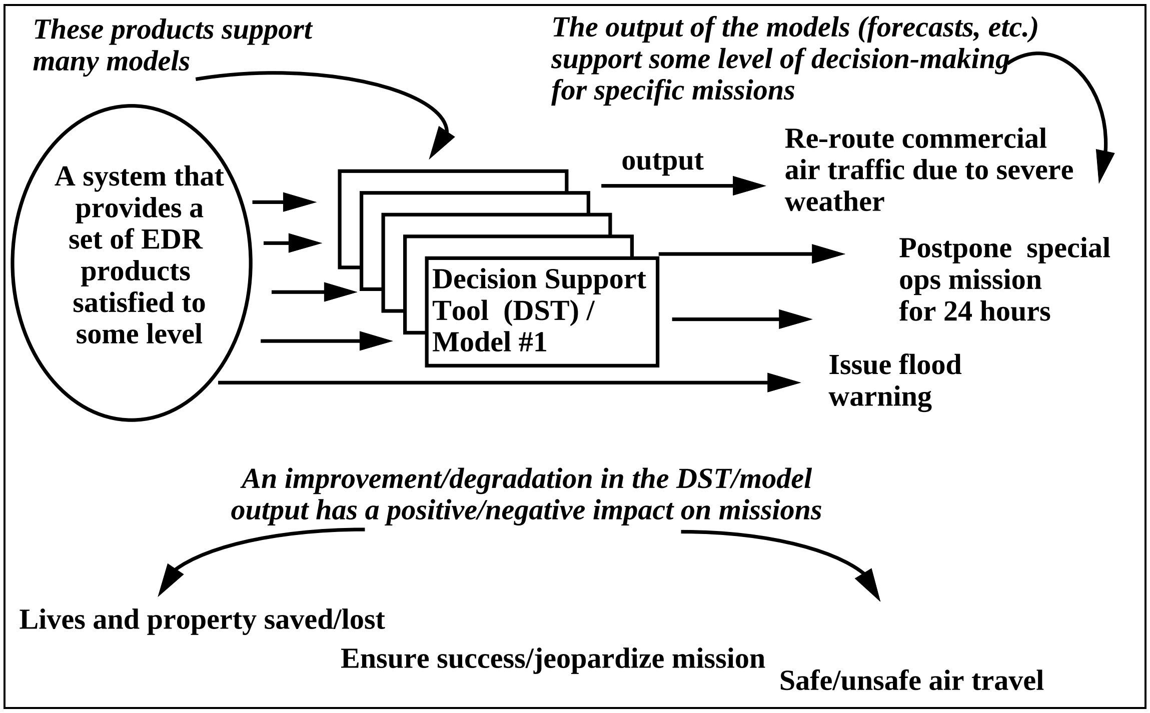

Figure 4-2. Weather Product Generation, Use and Impact

For NOAA, instrument enhancements are typically based on scientific understanding of the weather products, their use, and the method of obtaining the data. Often, improvements in weather products are required to keep up with the fidelity of models (i.e., data less accurate than the fidelity of the models required would, at least, introduce errors into the analysis and, at worst, would be completely useless). Consequently, quantitative operational benefit models have not been required to support NOAA's requirements process, and therefore, such models do not exist for even very specific civilian weather products and missions.

On the military side, years of studies have been conducted to show the contributions of weather to a variety of military missions. For example, studies by the General Research Corporation (GRC) include: a utility analysis to show the value of soil moisture forecast data on trafficability for the Army; an analysis of the impact of cloud cover and visibility forecast accuracy on tactical air strike effectiveness, and; weather impacts on Army weapon systems. More detailed discussions of the results of these analyses appear in Appendix E as they relate to specific EDRs. However, after a survey of existing models and studies, none support the EDR differences among the COBRA alternatives. Most military weather products are required to support tactical situations (i.e., accurate weather data is required for mission planning in relatively small areas) or are driven by weapons system requirements.

The operational benefit analysis for the COBRA, then, is a qualitative analysis, based on the wealth of knowledge and experience of NOAA and DoD scientists and users. As they were available, studies that support the need for the weather products were evaluated for specific application to the NPOESS COBRA. To supplement and build on the information contained in this documentation, user data was gathered via one-on-one interviews. This user information, together with information gleaned from the various studies, identified deficiencies in current environmental data collection and highlighted the contribution of various weather products to specific missions. This information was used to develop/support the operational benefit assessments for each of the COBRA alternatives. In addition, usage information relating to all NPOESS EDRs is summarized in Appendix E. As quantitative studies were available, results and/or supporting information from these were included as well.

Other sources of weather data contribute to mission success depending upon what the mission is and, for DoD, in which area they are operating. We have considered these other sources only as they are substitutes for data from polar-orbiting satellites, primarily from a limitations aspect. These are addressed as part of Appendix G, as applicable.

The results of the operational benefit analysis are presented as color ratings, reflecting the extent of risks and limitations that are likely to be experienced by the user community for each alternative. These risks and limitations reveal the impacts to specific user missions due to lack of specific IORD-I EDRs provided by the alternative. The risks are expressed in the context of five functional categories summarized from the 14 functional areas delineated in IORD-I, Section 1.2. These five functional categories were developed by the users to simplify the analysis since only a small subset of NPOESS IORD EDRs were being considered in comparing the COBRA alternatives and since many of these areas can overlap depending upon subjective interpretation. The mapping of these 14 functional areas to the five summary-level categories appears in Table 4-1. Four of the five categories apply to NOAA only.

Table 4-1. IORD-I Mapping: Functional Areas to Functional Categories

	NOAA Only				DoD Only
IORD-I Functional Areas	Forecasts and Warnings	Oceans and Ice	Solar and Space Environment	Climate	Military Unique Applications
Aviation Forecasts	X				
Medium Range Forecast Outlook	X				
Tropical Cyclone Warnings	X				
Severe Storm & Flood Warnings	X				
Forecasts of Ice Features		X			
Solar & Space Environmental Forecasts			X		
Hydrologic Forecasts		X			
Forecasts of the Ocean Surface & Internal Structures		X			
Seasonal & Interannual Climate Forecasts				X	
Decadal Scale Monitoring of Climate Variability				X	
Assessment of Long-term Global Environmental Change				X	
Environmental Air Quality Monitoring & Emergency Response				X	
Tactical Decision Aids					X
Weapon Systems Utilization					X

The color rating assessments (also referred to as a stop light chart) were determined by the users. A rating of "Red" was given to a functional category for an alternative if impact to one or more missions was critical (i.e., there exist severe limitations and risks or there is complete mission failure). "Yellow" was assessed if impact to one or more missions was not critical but some limitations and risks still exist. Finally, "Green" was assessed if all relevant missions were able to be accomplished without limitations and risks. All military missions and related EDRs are considered under the single functional category Military Unique Applications (MUA) while NOAA missions and related EDRs were considered under the remaining four categories. This allows the impact of unique service/agency risks and limitations to be delineated and understood. The results of the analysis appear in Section 4.2.2. Lack of any P^3I EDR is never considered to impact any function area in a critical fashion (i.e., lack of these EDRs can't turn any functional category "Red") since the users have agreed that these parameters are at best technically difficult to achieve in the NPOESS timeframe.

4.2 RESULTS

This section separately discusses the life cycle cost analysis and the operational benefit analysis results.

4.2.1 Life Cycle Cost Analysis Results

Tables 4-2 summarizes the LCC for the four COBRA alternatives in FY 96, and TY dollars. Since the focus on the COBRA was on payload differences, sensor life cycle cost estimates that are part of the space segment estimate are presented in Appendix F. The COBRA cost estimates are single point estimates and should be considered to be the "most likely" LCC for a given notional alternative. As stated in Section 4.1.1, these costs were developed using a systems engineering/cost analysis process and they lack the rigorous documentation associated with a full Program Office Estimate (POE). Supporting documentation containing detailed cost estimate methodologies and justification appears in Appendix F.

[Table 4-2, 4-7, and Appendix F have been deleted from this report since they contain Government Cost Information which may no longer be representative of the current NPOESS program.]

Table 4-2. Summary Life Cycle Costs for COBRA Alternatives

[Table 4.2 has been deleted from this report since it contains Government Cost information which may no longer be representative of the current NPOESS program.]

The objective of this COBRA was to evaluate the operational capabilities of notional NPOESS alternatives that were defined by three cost targets: low cost (Alternative 1) $7.1B TY; medium cost (Alternative 2) $7.8B TY, and high cost alternatives (Alternatives 3A and 3B) $9.1B TY. As Table 4-2 shows, these targets have been achieved with the identified alternatives.

Total life cycle costs contain development, production and operations and support costs. Development costs cover the costs associated with design, development and testing of all system segments (i.e., space segment, launch support segment, C^3 segment, and IDP segment). The significant differences in development costs across the alternatives are due primarily to sensor development. Production costs include the cost to procure sensors to support operational availability requirements specified in IORD-I. Operations and support (O&S) costs cover a 10 year period after IOC, and includes personnel and O&S costs associated with making the ground segments operational for the period prior to system IOC. Significant differences in O&S costs across the alternatives are due primarily to processing of sensor data and survivability impacts to the ground segments.

4.2.2 Operational Benefit Analysis Results

The operational benefit analysis considered only the differences in the four COBRA alternatives, 16 EDRs, against the five functional categories. Assessments were made by the users as to which of these 16 EDRs significantly impacted one or more of the five functional categories. This mapping is provided in Table 4-3. Although other relationships between EDR and functional categories may exist, they were not considered significant enough to warrant discussion in this study.

Table 4-3. Mapping of Difference EDRs to Functional Category

COBRA EDRs	Forecasts & Warnings	Oceans & Ice	Solar & Space Environment**	Climate	Military Unique Applications
Ocean/Water					
Currents		X		X	X
Littoral Sediment Transport		X			X
Ocean Color/Chlorophyll		X		X	X
Turbidity		X			X
Ocean Wave Characteristics		X			X
Sea Surface Height/ Topography		X			X
ERB					
Downward Longwave Radiation				X	
Insolation				X	
Total Longwave Radiation (TOA)				X	
Net Shortwave Radiation (TOA)				X	
Solar Irradiance				X	
P^3I*					
Tropospheric Winds	X				X
Enhanced Ozone				X	
Methane (CH_4)				X	
Carbon Monoxide (CO)				X	
Carbon Dioxide (CO_2)				X	

* Optical backgrounds, bathymetry, bioluminescence and salinity were not considered by the COBRA.

** Not addressed by the COBRA since all EDRs impacting this category are satisfied by all alternatives.

Results of the operational benefit analysis of each by alternative across the five functional categories appear in Table 4-4. The color assessments, as described in Section 4.1.2, are based on the presence (at IORD-I specified threshold levels) or absence of one or more of the 16 EDRs relevant to missions that fall into each of the five functional categories. One or more missions were considered within each functional category, so these color ratings represent an overall assessment. The ground rules used to develop these assessments are as follows:

- It is the user's operational assessment that distinguishes unacceptable versus marginal versus acceptable mission accomplishment in the absence of critical weather products. This information has been taken from existing studies and/or elicited from users.

- Within a functional category, if only one mission is found to suffer severely from the lack of critical weather data, (consequently the alternative would be rated as "Red" for that mission) then the overall functional category assessment will be rated "Red". (Similarly if the worst rating for a functional category is "Yellow".) Thus the worst rating across a set of missions is adopted as the overall assessment for that functional category.

Table 4-4. Operational Benefit Analysis Summary by Functional Category

	ALT 1*	ALT 2 (IORD-I)	ALT 3A	ALT 3B
Life Cycle Costs (TY $B)	$7.1	$7.8	$9.1	$9.1
Operational Benefit Functional Categories				
Forecasts and Warnings (F&W)	Yellow	Yellow	Green	Yellow
Oceans and Ice (O&I)	Yellow	Green	Green	Green
Solar and Space Environment (S&SE)	Green	Green	Green	Green
Climate (C)	Yellow	Yellow+	Yellow+	Green
Military Unique Applications (MUA)	Red*	Yellow	Green	Yellow

* Although the key system-level parameter and all key EDR attributes are met by this alternative, MUA is "Red" from a system-level perspective since it fails to satisfy "system survivability" and from an oceanographic (versus meteorological) perspective due to the severe impacts (including fatalities) that could result in specific Navy missions due to lack of currents and ocean wave characteristics at threshold levels (see Appendix G).

The detailed rationale for the assessments for the COBRA alternatives appear in Appendix G. A summary discussion of these assessments is provided here.

The inability to provide specific EDRs related to altimetry, ocean color, earth radiation budget (including solar irradiance), tropospheric winds, enhanced ozone and trace gases degrade the ability of the users to support missions and, therefore, impacts the relevant NPOESS functional categories. Note that tropospheric winds, enhanced ozone and trace gas EDRs are requirements in IORD-I that at this time are specially categorized as potential P^3I requirements.

With the addition/improvement of sensors that provide altimetry, earth radiation budget and ocean color EDRs to Alternative 1, and the inclusion of system survivability, Alternative 2 meets all IORD-I requirements at the threshold level (other than the P^3I assessments previously discussed). Impacts to three of the five NPOESS functional categories are lessened as can be seen from the overall assessments (color ratings) in Table 4-4. Alternatives 3A and 3B each incorporate specific P^3I EDRs, tropospheric winds and trace gases/enhanced ozone, respectively, thereby improving the related functional categories. The next section provides additional information, by functional category, related to the color ratings of each alternative presented in Table 4-4. The rationale behind each is provided in Appendix G.

4.2.2.1 Operational Benefit Assessments by Functional Category

The operational benefit assessments (color ratings) for the COBRA alternatives, shown in Table 4-4, are presented below by the functional categories. Discussion follows to summarize how color assessments change from alternative to alternative. Note again, that lack of any P^3I EDR is never considered to impact any functional category in a critical fashion (i.e., lack of these EDRs can't turn any functional category "Red") since the users have agreed that these parameters are technically difficult to achieve in the NPOESS timeframe.

Forecasts and Warnings. For the functional category, Forecasts and Warnings, the overall assessments for the COBRA alternatives are:

- Alternative 1 Yellow
- Alternative 2 Yellow
- Alternative 3A Green
- Alternative 3B Yellow

The single EDR driving the distinction among alternatives in this functional category is tropospheric winds, provided only in Alternative 3A with the inclusion of lidar. Since winds steer weather and drive the climate, more accurate wind data will have substantial benefit to all civilian and military users. Benefits include: improvement in forecasts; improvement in storm and hurricane warnings; and, economic savings in fuel consumption for airlines.

Although it is acknowledged by the weather community that improvement in wind data is vital, the technological maturity of lidar is an issue. Consequently, the users have accepted directly measured tropospheric winds to be a P^3I requirement. Hence the operational benefit assessment for those alternatives where this EDR is not provided is “Yellow”, as opposed to “Red”.

Oceans and Ice. For the functional category, Oceans and Ice, the overall assessments for the COBRA alternatives are:

- Alternative 1 Yellow
- Alternative 2 Green
- Alternative 3A Green
- Alternative 3B Green

The addition of ocean and water parameters provided by the ocean color/chlorophyll enhancement to the imager and by the altimeter in Alternative 2, over Alternative 1, improves the overall operational benefit assessment from Yellow to Green. Measurement of currents contributes to the long-term understanding of biological sustainability of U. S. fishing resources, and provides better open ocean information for commercial shipping. Measurements of turbidity and littoral sediment transport contribute to trafficability assessments and the understanding of marine environmental quality for biological production. Ocean color measurement contributes to the understanding of plant pigment concentrations in the open ocean. Understanding ocean wave characteristics are vital to generate wave forecasts for small craft advisories and storm surges.

The lack of these EDRs from polar orbiting satellites was not viewed by the users as a mission critical limitation for civilian missions (i.e., there would not be complete mission failure without these EDRs, which would cause this evaluation to be “Red”). Thus, the overall assessment of operational benefit without these EDRs is “Yellow”.

Solar and Space Environment. For the functional category, Solar and Space Environment, the overall assessments for the COBRA alternatives are:

- Alternative 1 Green
- Alternative 2 Green
- Alternative 3A Green
- Alternative 3B Green

All alternatives satisfy this functional category to IORD-I threshold levels so that the operational benefit assessment is "Green".

Climate. For the functional category, Climate, the overall assessments for the COBRA alternatives are:

- Alternative 1 Yellow
- Alternative 2 Yellow+
- Alternative 3A Yellow+
- Alternative 3B Green

Alternative 1 is assessed as "Yellow" due to the risks and limitations associated with the inability to measure ERB EDRs to IORD-I threshold levels (including solar irradiance) and P^3I high-resolution ozone profile and trace gas EDRs (carbon dioxide, carbon monoxide and methane). ERB information is important to our understanding of energy emitted from the earth and determining solar influence on the earth. Determination of high resolution ozone profiles and related trace gases is vital to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate. Although the operational collection of this information to IORD-I threshold levels from a polar-orbiting satellite has a significant mission impact, Alternative 1 is assessed as "Yellow" and not "Red" primarily due to (low resolution) ozone column and a limited (reduced) capability to measure certain ERB parameters with the imager/radiometer and sounding suites.[35]

The improvement from “Yellow” in Alternative 1 to “Yellow+” in Alternatives 2 and 3A is due to the addition of ERB (including solar irradiance) measurement capability. Neither Alternative 2 nor 3A was assessed as “Green” since each lacks enhanced ozone and trace gases measurement capability (as did Alternative 1). Alternative 3B is assessed as “Green” due to its ability to provide, in addition to the ERB parameters, high resolution ozone profile and trace gas EDRs.

Military Unique Applications. This functional category contains all military operational impacts. For the functional category, Military Unique Applications, the overall assessments for the COBRA alternatives are:

• Alternative 1	Red
• Alternative 2	Yellow
• Alternative 3A	Green
• Alternative 3B	Yellow

The operational assessment of “Red” for Alternative 1 is specifically due to the lack of ocean/water EDRs, in particular, the lack of current and ocean wave characteristic data from the altimeter. Accurate current and wave characteristic data on a global scale is vital to Navy operations, and current data, provided by buoys and fly-overs for very localized regions, are severely limited. Lack of real-time data on some ocean phenomena (e.g., eddies) can be fatal as environmental conditions can be exploited by hostile forces for tactical purposes. Lack of these ocean/water EDRs was assessed by the users as critically limiting military missions. In addition to the EDR requirements described above, Alternative 1 does not satisfy the DoD system-level

[35] Note: The users have accepted high resolution ozone profile and trace gas measurements as P^3I requirements based on Phase 0 contractor studies that indicated spacecraft accommodation/technical feasibility issues for sensors/monitors associated with these capabilities. For more information on the technical aspects of these P^3I capabilities, see: White Paper on “Issues related to NPOESS IORD-I Potential Pre-planned Product/Process Improvements, D. Blersch, NPOESS IPO, 9 May 1996

requirement for "system survivability". Thus, in the event of an intentional or unintentional occurrence of one of the "threats" described in Section 1.2 of this report, some or all of the NPOESS performance capability could be degraded or lost completely.

Alternatives 2, 3A, and 3B all satisfy the "system survivability" requirement, thus making EDR satisfaction the only determinant of operational benefit for these alternatives. With the addition of ocean/water EDRs from Alternative 1 to Alternatives 2 and 3B, the color assessment changes from "Red" to "Yellow". The "Yellow" assessment is attributed to the lack of tropospheric wind data, for similar reasons cited for civilian missions. As with the civilian missions, accurate wind data is vital to weather prediction, and accurate knowledge of weather and the environment can be exploited/countered for military missions (e.g., paratroop operations).

Alternative 3A includes tropospheric winds as well as the ocean/water EDRs, so that the operational assessment for that alternative is "Green".

4.3 TRADE-OFF ANALYSES AND OTHER STUDIES

As mentioned in Section 3.3, many trade-offs were conducted involving architectures, performance, and cost during the IORD-I and COBRA alternative definition process. Other cost sensitivity analyses were performed as "quick-look" studies to address specific trade-off areas of interest to the COBRA team. These areas included some of the system elements common to all alternatives which constitute significant cost elements. These analyses are discussed in the following sections. Further analysis may be performed at a later date in each trade-off area to provide detail on the operational benefit impact of the technical performance degradation associated with cost savings.

4.3.1 IR Sounder Cost Versus Performance (Measurement Accuracy)

During the course of the IORD-I development process, it was determined that a sounding suite (consisting of IR and various microwave sensors) capable of satisfying user requirements could be accommodated within the cost saving targets which define the various COBRA alternatives. Due to the critical nature of the sounding mission, this sounder suite configuration was “fixed” across the COBRA alternatives as part of the overall cost/benefit trade-space. In addition, sensitivity analyses show that while performance variations for the various IR sounding instruments under consideration will have significant impacts on the satisfaction of various user requirements, the associated total system life-cycle cost impact will be relatively small (i.e., marginal potential for cost savings while introducing significant technical performance shortfalls to the system). The data (cost and performance) that supports this conclusion are presented in this section.

The IR sounder gathers information that is used in combination with other sensors. It is a vital environmental data product source that contributes to the production of several key EDRs and derivation of many other EDRs. The EDR products that to varying degrees rely-on/incorporate, as part of their generation, IR sounder-type data are listed in Table 4-5.

Table 4-5. IR Sounder-Type Data EDR Crosswalk

EDRs Generated with IR Sounder Data as a Primary Data Product Source	EDRs Generated with IR Sounder Data as a Secondary (and/or ancillary) Data Product Source
Vertical Moisture Profile (Key)	Sea Surface Temperature (Key)
Vertical Temperature Profile (Key)	Precipitation Type/Rate
Precipitable Water	Cloud Cover/Layers
Pressure (Surface/Profile)	Cloud Effective Particle Size
	Cloud Optical Depth/Transmittance
	Cloud Top Height (Derived)
	Cloud Top Pressure (Derived)
	Cloud Top Temperature
	Net Heat Flux

As part of the COBRA sensitivity analysis, three performance levels were chosen for the sounding mission in terms of their ability to satisfy IORD-I requirements. These performance levels span a range of capability offered by the notional IR sounder baselined in the COBRA alternatives (known as the Interferometer Thermal Sounder or "ITS") and two other IR sounder "candidates" examined during the IORD-I development process (the High Resolution Infrared Radiation Sounder/3 or "HIRS/3" - IR sounder currently baselined to fly on NOAA K-N' spacecraft, and the Advanced Infrared Sounder or "AIRS" - baselined to fly on NASA's EOS-PM-1 spacecraft). These three IR sounders are shown in Table 4-6, along with their projected performance capability with respect to IORD-I thresholds (color assessment), when used in combination with the other sensors baselined in the COBRA (and held constant in this comparison). The primary performance difference between these IR sounder candidates is absolute measurement accuracy for narrow vertical swaths (layers) of the atmosphere. The measurement accuracy for each EDR required by the users and documented in IORD-I appears with the EDR name. The assessment (color rating) of the performance provided by each of the IR sounder candidates for each EDR is provided in the IR sounder columns.

As shown in Table 4-6, degrading the IR sounder (i.e., switching from ITS to HIRS) has a negative impact to EDR satisfaction. Both the ITS and AIRS, when flown in conjunction with the Advanced Microwave Sounding Unit (AMSU), meet (or exceed) all IORD-I thresholds. The HIRS would only meet the key attribute thresholds for atmospheric vertical temperature and moisture profiles while failing to meet some of the non-key attributes of these "key" parameters (such as sampling interval), as well as other "non-key" EDRs.

Table 4-6. Comparative IR Sounder Performance for Impacted EDR Data Products

EDRs	IR Sounder COBRA (“ITS”)	IR Sounder (“HIRS/3”)	IR Sounder (“AIRS”)
Key parameters:			
Vertical Moisture Profile *Measurement Accuracy (Surface to 600mb) +̲20%*	Blue *Blue*	Yellow *Green*	Blue *Blue*
Vertical Temperature Profile *Measurement Accuracy (Surface to 300mb) +̲1.6K*	Blue* *Blue*	Yellow** *Green*	Blue*** *Blue*
Atmosphere EDRs:			
Precipitable Water	Green	Yellow	Green
Pressure (Surface/Pro)	Green	Yellow	Green
Cloud EDRs:			
Cloud Top Height	Green	Yellow	Green
Cloud Top Pressure	Green	Yellow	Green
Ocean/Water EDRs:			
Net Heat Flux	Green	Yellow	Green

* 1.0 K “ITS/AMSU” combined performance

** 1.6 K “HIRS-3/AMSU” combined performance

*** < 1.0 K “AIRS/AMSU” combined performance. Note AIRS/AMSU performance may “exceed” color values indicated.

Note: all other payload instruments remain unchanged.

Key: Blue = exceeds IORD-I threshold, Green = meets IORD-I threshold, Y = below IORD-I threshold.

As seen in Table 4-7, the life cycle cost for each of the IR sounders under consideration varies only slightly, and thus has an insignificant impact on the total system LCC. This small difference in LCC is well within the overall error of the estimate. Thus, this sensitivity analysis shows that the performance differences for the various IR sounding instruments under consideration have significant impact on the satisfaction of user requirements and a relatively small LCC impact. This cost insensitivity indicates the IR sounder is not a “high payoff” cost/performance trade-off area. Considering the significant contributions made by the IR sounder to the accomplishment of the users' missions, it would not be prudent to decrease performance in this area.

Table 4-7. Costs for Candidate IR Sounders (FY96 Millions of Dollars)

[Table 4.7 has been deleted from this report since it contains Government Cost Information which may no longer be representative of the current NPOESS program.]

4.3.2 Constellation Size

With other constraints, assumptions, and guidance fixed, the single most significant remaining cost driver is the number of orbits, which drives the number of satellites and, in turn, sensors required. The COBRA process showed that a three-ball constellation (i.e., an 0530 NPOESS orbit, a 1330 NPOESS orbit, and a 0930 EUMETSAT orbit) was affordable within the severest cost constraint ($2.0B savings). Furthermore, Alternative 2 meets the $1.3B National Performance Review cost savings target while satisfying all of the requirements at the threshold level, except for the P^3I EDRs. Consequently, all COBRA alternatives reflect a three-ball constellation.

4.3.2.1 Three-Ball Constellation (COBRA Rationale)

In addition to the affordability and performance issues, the COBRA team considered the following factors in determining that a three-ball constellation was the preferred approach for NPOESS.

1) U. S. Control

   The Acting Chairman of the Joint Chiefs of Staff stated that the Joint Staff "position is that at least two satellites in a converged system constellation must be U. S.-controlled to meet key DoD requirements."[36] This was reaffirmed by the Director of the Joint Staff.[37]

[36] CM-55-93, 6 December 1993, "Assessment of Alternatives for the Satellite Constellation in a Converged National Polar-Orbiting Environmental Satellite System

[37] DJSM-1361-93, 20 December 1993, "Convergence of the Defense Meteorological Satellite Program With the Polar-Orbiting Operational Environmental Satellite and the Earth Observing System Programs.

2) Assured Access

The Presidential Decision Directive states that "Assured access to operational environmental data will be provided to meet civil and national security requirements and international obligations."[38] This reinforces item (1), above.

3) METOP

METOP-3 will fly in the 0930 orbit. The nodal crossing time of METOP was set after years of negotiation between NOAA and EUMETSAT and is not subject to change. Furthermore, the Acting Chairman of the Joint Chiefs of Staff stated that "The technical requirement for a 4-hour cloud imagery refresh rate can be met if a foreign satellite is in the 0930 orbit and the United States budgets for the capability to augment that satellite should data from it be unavailable to the United States for any reason."[39]

4) Refresh

The Acting Chairman of the Joint Chiefs of Staff stated that "The DoD-required overall average cloud imagery refresh rate is 4 hours, which requires a 3-satellite constellation."[40] (Note that this is also one of the IORD-I requirements on imagery that will be discussed later in this section.) The natural temporal scale sizes of many weather phenomena are shorter, sometimes significantly shorter, than can be adequately forecast by a 6 hour refresh, thus necessitating a need for weather updates within two hours (or less) of a theater operation. NOAA has a similar requirement for short term severe weather warnings.

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[38] Presidential Decision Directive/National Science and Technology Council (PDD/NSTC-2), Section II, page 2, 5 May 1994

[39] CM-55-93, 6 December 1993, "Assessment of Alternatives for the Satellite Constellation in a Converged National Polar-Orbiting Environmental Satellite System

[40] CM-55-93, 6 December 1993, "Assessment of Alternatives for the Satellite Constellation in a Converged National Polar-Orbiting Environmental Satellite System

5) Time of Phenomena/Observation

The discussion in Appendix D shows that many EDRs need to be collected at specific times for various reasons. Some examples of this are:

<u>0530 Orbit</u>

- SES pre-sunrise and pre-sunset (i.e., the terminator) ionosphere collections of scintillation effects and electric field/potential are required for determining equatorial spread-F conditions which can affect communications and have a direct impact on tactical operations. This particular SES data is used to forecast/send out warnings on ionospheric effects which lead to C^3I outages (the 0930 and 1330 orbits cannot be used for this particular purpose because this data is only available near the terminator). Enough warning time allows outage minimization strategies to be developed.
- The (low light level) pre-dawn collection for the military is essential to support tactical missions planned for daylight hours.
- Current ACRIM design requires a 20 minute staring measurement of solar irradiation. (An accurate pointing and tracking mechanism would have to be implemented if the ACRIM was flown in a 0930 or 1330 orbit.)

<u>0930 Orbit:</u>

- Shows the plasma depletions that contribute to scintillation and impact high frequency and satellite communications.

<u>1330 Orbit:</u>

- Ozone collection and ocean color require the high solar illumination of this orbit. Solar illumination in mid to late afternoon orbits would be too low to enable monitoring of ozone or ocean color.
- Persistent buildup of cloud cover during the day restricts the ability to see the earth’s surface later in the afternoon (e.g., 1530 or later orbits).
- Provides best night time view (determination) of the auroral oval boundary by the SES auroral imager. This input is used by the magnetospheric specification model. (The SES instruments see the auroral boundary in all orbits.)
- Orbit provides eastern pacific data when needed to support development of 00Z and 12Z synoptic analyses.
- Orbit allows for overall data continuity with NOAA weather models.

With respect to performance, IORD-I, Section 4.1.6.1.3, identifies three requirements for imagery refresh (a key requirement and attribute), that are drastically impacted by constellation size. These imagery refresh requirements are:

a) the average revisit time will be four hours or less;
b) the maximum revisit time will be six hours or less; and,
c) at least 75 percent of the revisit times will be four hours or less.

To demonstrate that the three-ball constellation, as configured for all the COBRA alternatives, satisfies these imager refresh requirements, the Aerospace model REVISIT[41] was used. This model used a Walker 3/3/2 constellation at 833 km with an imager having a 56.2 degree nadir angle. The three orbits used are 0530, 0930 and 1330. For this constellation, it takes 31 days for the ground tracks to repeat themselves. The model used a three degree grid.

Figure 4-3 displays the average revisit times for the 31-day period, as well as the maximum revisit time for each latitude. These data show that the three-ball constellation will satisfy parts a) and b) of the IORD-I refresh requirement with significant margin.

[41] Clifton, R. S., “Preliminary REVISIT User’s Manual,” ATM 93 (9975)-6, Oct. 21, 1992.

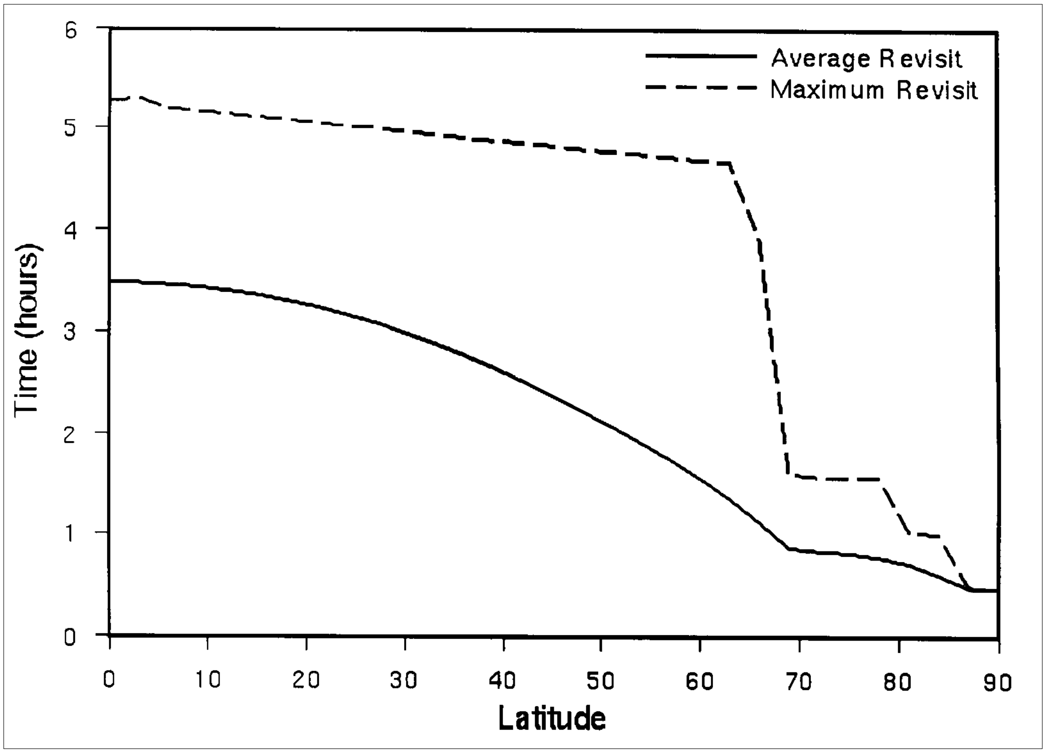

Figure 4-3. Average and Maximum Revisit Time vs. Latitude for a Three-Ball Constellation

Figure 4-4 shows a further breakout of the average revisit data, describing the global distribution, expressed as a percentage of the earth's surface covered, for specific one hour revisit intervals. For example, 31.6 percent of the earth's surface is revisited at an interval ranging between two and three hours. (Note that the hourly intervals are independent, i.e., the sum of the four intervals shown equals 100 percent.) Figure 4-5 shows the same breakout for the maximum revisit times.

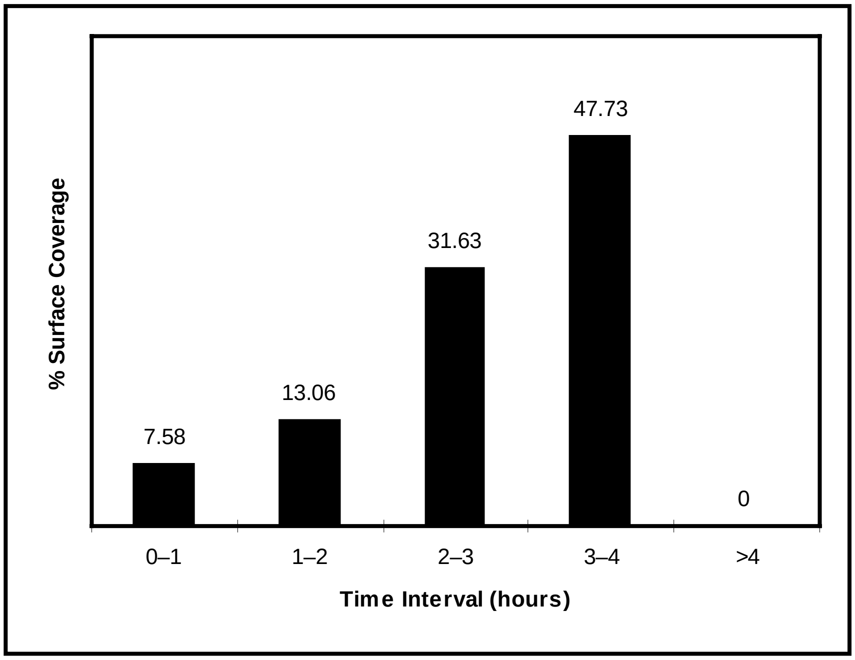

Figure 4-4. Earth Surface Coverage vs. Average Revisit Time for a Three-Ball Constellation

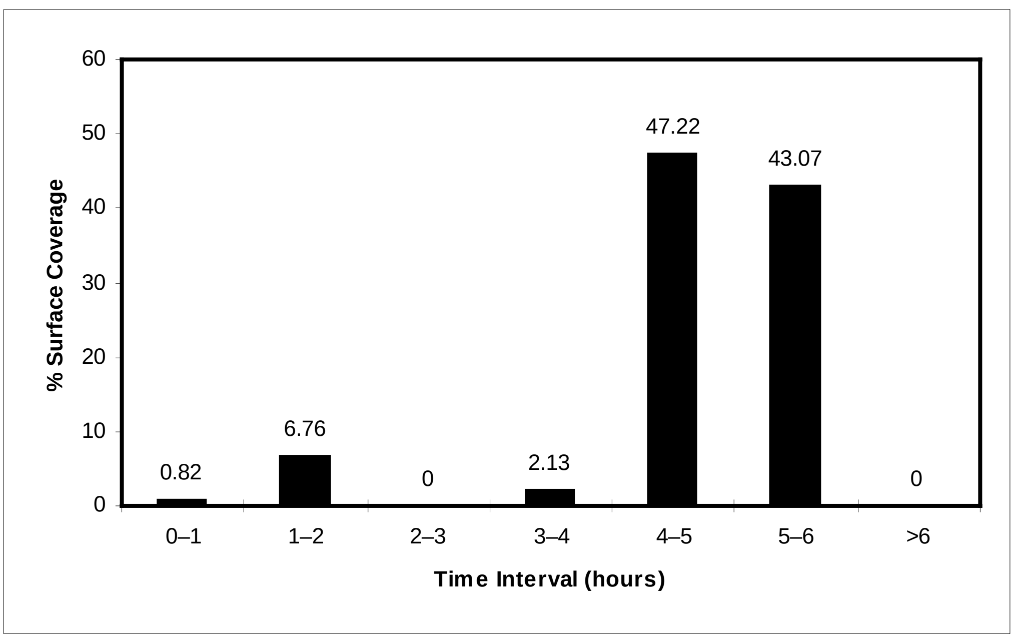

Figure 4-5. Earth Surface Coverage vs. Maximum Revisit Time for a Three-Ball Constellation

Note that the maximum revisit histogram (Figure 4-5) is generated from the single maximum revisit times from the total 31-day distribution for each location. As an example, Figure 4-6 gives the distribution of revisit times for a given latitude and longitude in the Washington D. C. area. Note that for this location, the revisit times (approximately 300) occurring during the 31-day period range from 30 minutes to five hours. In generating the maximum revisit time histogram (Figure 4-5) only the single maximum (five hour) refresh time from this particular location was included.

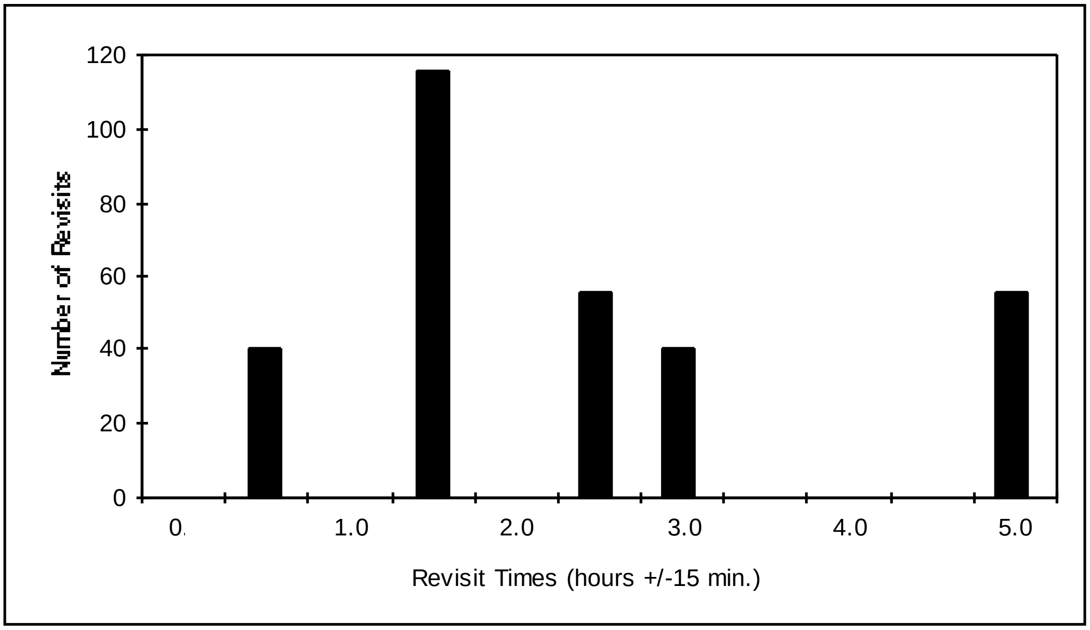

Figure 4-6. Distribution of Revisits vs. Revisit Times for a Single Location

Figure 4-7 shows that part "c" of the imagery refresh requirement (at least 75% of the revisit times will be 4 hours or less) is met with the three-ball constellation. This figure shows the distribution of the shortest 75 percent of all of the revisit intervals over a 31-day period, taken from the individual location distributions as described in Figure 4-6. This figure shows that, for the shortest 75 percent of the revisit times during the 31 day period, a four hour or less refresh rate was maintained globally.

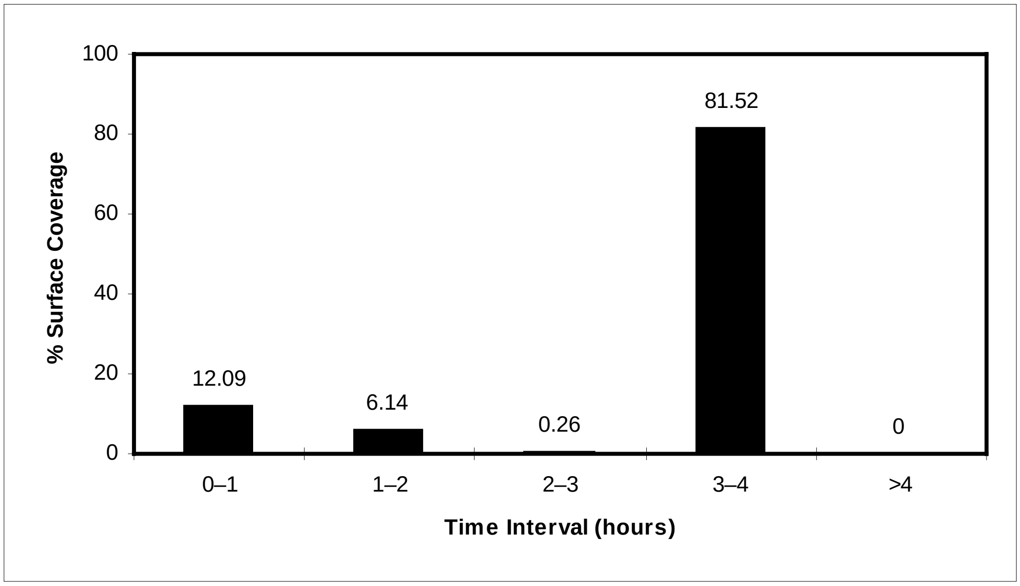

Figure 4-7. Earth Surface Coverage vs. Shortest 75 Percent of the Revisit Times for a Three-Ball Constellation

4.3.2.2 Other Constellation Sizes

Although aware of the rationale in sections 4.3.2 and 4.3.2.1, PA&E requested the IPO to look at several other constellation alternatives.

One-Ball Constellation. As no additional guidance was provided by PA&E, the IPO assumed that this system would consist of a single U. S. satellite without METOP. Regardless of which orbit one selects, it violates items 1 through 5 of Paragraph 4.3.2.1. Therefore, it would not meet many of the IORD-I requirements, even if a single spacecraft large enough to hold all of the required instruments was built. Furthermore, even if one assumed a “24 hour” refresh requirement, as long as the users cannot tolerate a “gap” in data, for data continuity or other reasons, then a second satellite is required on-orbit as a “hot spare” in event of an instrument failure on the primary satellite. The IPO considers the one-ball constellation to be an unacceptable solution and therefore has done no further analysis for this configuration. NOAA also considers this an unacceptable solution for POES.

Two-Ball Constellation. Again, since no additional guidance was given by PA&E, the IPO has assumed that this architecture would consist of a single U. S. satellite plus one METOP satellite. With only one U. S. spacecraft in orbit, a U. S. failure would mean no U. S. satellites in orbit until a replacement could be launched and deployed, placing the nation's citizens, property and security in jeopardy. An estimate of the cost of a two-ball constellation is shown at the end of this section. For this trade-off exercise, it was assumed that the 0530 U. S. orbit was eliminated. Again, eliminating this orbit violates items 1 through 4 of paragraph 4.3.2.1, and a portion of item 5 (the 0530 requirements). Table 4-8 shows the sensors that would be affected if the Alternative 2 architecture were assumed but the 0530 orbit was eliminated.

Table 4-8. Comparison of Payload and Implementation (with and without the 0530 orbit)

Notional COBRA Sensors	ALT 2 with 0530 orbit	ALT 2 without 0530 orbit
VIS/IR Imager Radiometer w/Ocean Color	a,b,c	b,c
Low Light VIS Imager	a,b,c	b,c
Cross-track IR sounder	b	b
Cross-track MW Temperature Sounder	b,c	b,c
Conical MW Imager/Sounder	a,b,c	b,c
Ozone Monitor	b	b
Data Collection System	a,b,c	b,c
Search and Rescue	a,c	c*
Space Environmental Suite (SES)	a,b,c	b,c
Earth Radiation Budget Sensor	b	b
Solar Irradiance Sensor	a	none**
Radar Altimeter	a	none**

Based on notional system for costing purposes.
a, b, and c indicate which spacecraft a particular instrument is flying on, where
a = 0530 NPOESS orbit, b = 1330 NPOESS orbit, c = 0930 EUMETSAT orbit
* Current international agreements require U. S. to fly two Search and Rescue payloads (SARSAT)
** Accommodation is a major issue on the 1330 or 0930 orbits; no agreements exist with EUMETSAT for these instruments.

Table 4-8 shows that, with the elimination of the 0530 orbit, there is no solar irradiance or altimetry data (i.e., currents, ocean wave characteristics, sea surface height/topography) at all. In addition, there is no early morning measurement/refresh on several EDRs, including several key EDRs, due to their dependence on the imagers and sounders. Furthermore, the Air Force decommissioned its Typhoon Reconnaissance Squadrons in the Pacific based upon the fact that the Navy Typhoon forecasting center would get sufficient data from the SSM/I instruments on two U. S.-controlled satellites. If a two-ball system were established with METOP, the cost to re-commission the reconnaissance squadrons would have to be factored into the total cost to the Government. (The annual cost to operate a WC-130 squadron is approximately $ 18 million, not including the cost of the aircraft.)

Moving the 1330 orbit to 1530 would help smooth out the refresh, but would lead to a degradation in the EDRs which require a high solar incidence angle, unless sensor apertures were enlarged to increase instrument sensitivity enabling operation at lower sun angles. In addition to those cited in paragraph 4.3.2.1, item 5, EDR measurements which would be severely impacted due to the low sun angle include aerosol optical thickness, aerosol particle size concentration, albedo (surface), littoral sediment transport, radiation budget parameters (net heat flux, net short wave radiation), surface insolation, suspended matter, turbidity, and vegetation index.

Figure 4-8 shows the average and maximum revisit times vs. latitude for a two-ball constellation (i.e., the same constellation used for the three-ball system except with the 0530 satellite removed). Note that from 0 to about 40 degrees latitude, the average exceeds the IORD-I required four hour revisit time and that from 0 to about 60 degrees latitude, the maximum exceeds the IORD-I required six hour revisit time. Figure 4-9 shows that this breech of the average revisit requirement occurs for approximately 65 percent of the earth’s surface (versus zero percent for the three-ball constellation). In addition, Figure 4-10 shows that the maximum of six hour revisit is violated for more than 85 percent of the earth’s surface (versus zero percent for the three-ball constellation). These data show that the two-ball constellation fails significantly to meet parts “a” and “b” of the IORD-I imagery refresh requirement.

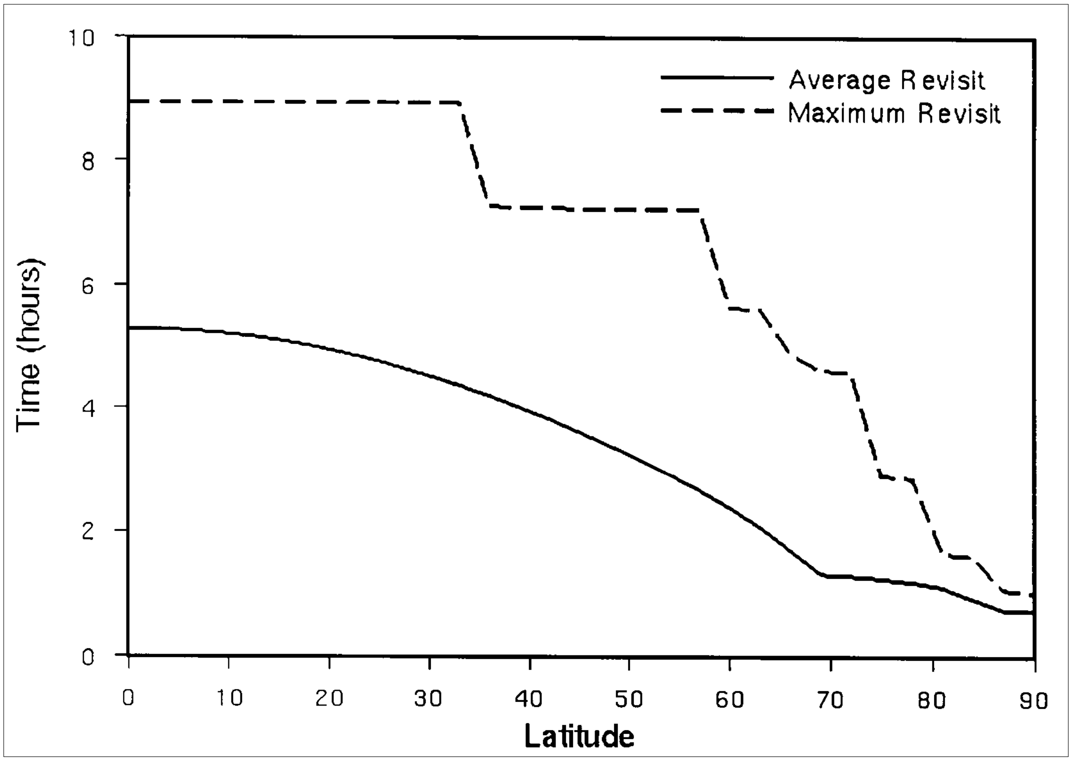

Figure 4-8. Average and Maximum Revisit Times vs. Latitude for a Two-Ball Constellation

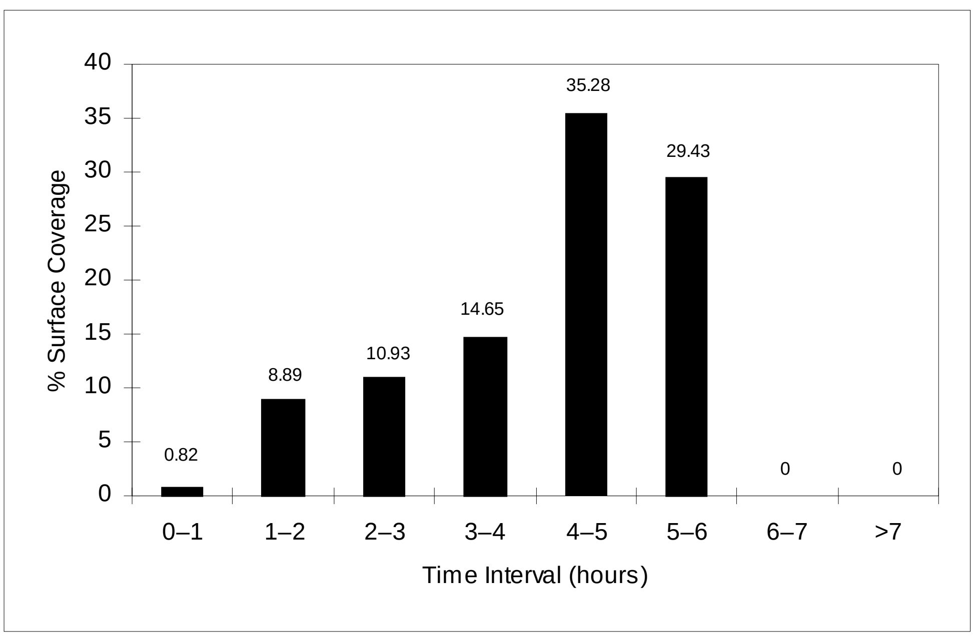

Figure 4-9. Earth Surface Coverage vs. Average Revisit Time for a Two-Ball Constellation

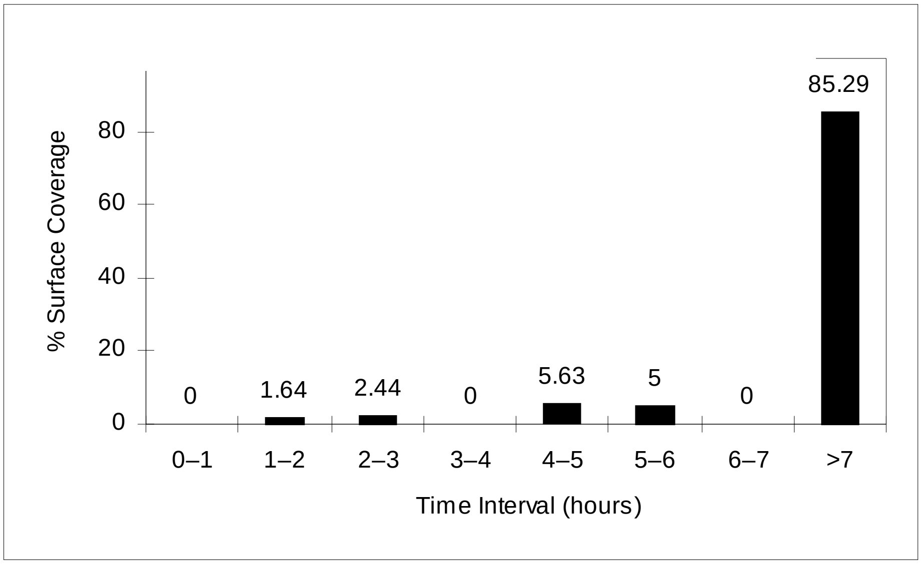

Figure 4-10. Earth Surface Coverage vs. Maximum Revisit Time for a Two-Ball Constellation

Finally, Figure 4-11 shows that part "c" of the IORD-I imagery refresh requirement is violated with a two-ball constellation. (Recall that the IORD-I requirement, part "c", constrains 75 percent of revisit intervals to be four hours or less.) With the elimination of the 0530 orbit, revisit intervals for only approximately 13 percent of the earth's surface are less than four hours, even when considering the shortest 75 percent of all individual location distributions.

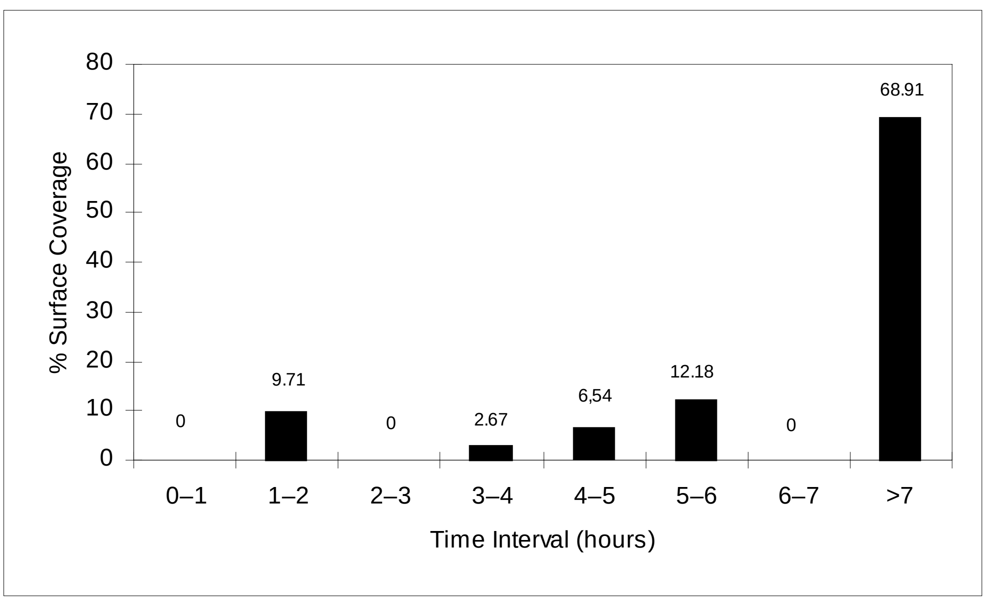

Figure 4-11. Earth Surface Coverage vs. Shortest 75 Percent of the Revisit Times for a Two-Ball Constellation

A rough-order-of-magnitude estimate of the cost of the two-ball constellation described here is $5,004M (FY96) [$6,851M TY], a savings of approximately $722M (FY96) [$988M TY] from the COBRA Alternative 2 estimate. These savings accrue from the deletion of two 0530 satellites and their associated launch, IDPS, and program office costs. (The C^3 and O&S costs were not changed for this estimate). Although these cost savings are not insignificant, the DoD would be unable to provide adequate, timely support with such a two-satellite system. In addition the loss of the single U. S. satellite would place the DoD in the position of being 100 percent reliant on the foreign EUMETSAT spacecraft for data, which is unacceptable for military customers.

4.3.3 Electro-optical Imager/Radiometer Cost Versus Performance (Resolution)

During the course of the IORD-I development process, it was determined that an electro-optical (EO) imager/radiometer instrument (consisting of various Visible (VIS), Infrared (IR), "low light" (LL) and Ocean Color (OC) channels) capable of satisfying user requirements could be accommodated within the cost saving targets which define the various COBRA alternatives. In the COBRA, the imager/radiometer instrument varied across the alternatives only with respect to the inclusion or exclusion of OC channels (OC was incorporated in Alternatives 2, 3A, and 3B, while not included in Alternative 1).

The VIS/IR/LL portion of the EO configuration was consequently "fixed" across each of the COBRA alternatives as part of the overall cost/benefit trade-space. The following discussion is therefore aimed at the cost/performance issues associated with this standardized piece of the EO system. In general, sensitivity analysis shows that while performance variations for the imager/radiometer portion of the EO instrument under consideration will have significant impacts on the satisfaction of various user requirements, the associated total system LCC impact will be relatively small (i.e., marginal potential for cost savings while introducing significant technical performance shortfalls to the system). The data (cost and performance) that supports this conclusion are presented in this section.

As background, it is important to note that the selection of the previously defined EO imager/radiometer was driven primarily by attempts to strike a technical balance in defining a notional sensor to adequately address the mission areas. Main areas of concern include spatial resolution, calibration/radiometric accuracy, and the number of channels/bands required to sense various environmental phenomena (clouds, snow, turbidity, etc.) In particular, two typically opposing features (imagery vice radiometry) must be melded together. Typically, “imaging” instruments are designed to have high spatial resolutions (at the expense of relatively low radiometric resolution/accuracy), making imagers capable of producing very high quality spatial scenes. “Radiometry” instruments are, on the other hand, typically optimized to detect selected weak-band electromagnetic radiation signals (that often resemble noise and are obscured by the receiver noise). Thus they tend to have a high radiometric resolution/accuracy at the expense of a relatively low spatial resolution. The EO instrument examined in the COBRA was designed to accommodate both radiometric accuracy and high resolution.

Specifically, the imager/radiometer sensor selection was based on technical results from the NPOESS Phase 0 studies (both contractor and government) as well as broader expertise provided by U. S. Government technical consultants, and earlier Block 6 and NOAA O,P,Q studies. Thus, the EO sensor used in the COBRA functionally captures within one instrument the operational “properties” making up the imager- and radiometer-type sensors that are now flown separately on DMSP and POES spacecraft. The EO sensor system described in the COBRA alternatives is thus a reasonable design point for addressing the user requirements in question, both from a technical and cost perspective.

The EO imager/radiometer is a critical instrument on the satellite which directly measures several key EDRs as well as providing information to derive many other EDRs. The list of EDRs that depend upon the imager/radiometer is given in Table 4-9. In general, all of the EDRs which rely on the imager/radiometer as a primary data product source (as well as most, if not all of the EDRs which rely on the EO instrument as a secondary data product source) would suffer if the performance (in terms of horizontal resolution, for example) were degraded. The imager/radiometer channels in the COBRA alternatives have an edge of scan resolution for all bands of .8 km, with .4 km resolution at nadir. Note this horizontal spatial resolution (HSR) value is the same level of imaging performance as obtained from the visible channel on the current DMSP 5D2/3 satellites.

Table 4-9. Imager/Radiometer-Type Data EDR Crosswalk

EDRs Generated with Imager/Radiometer Data as a Primary Data Product Source	EDRs Generated with Imager/Radiometer Data as a Secondary (and/or ancillary) Data Product Source
Imagery (Key)	Vertical Moisture Profile (Key)
Sea Surface Temperature (Key)	Vertical Temperature Profile (Key)
Soil Moisture (Key)	Sea Surface Winds (Key)
Aerosol Optical Thickness	Precipitation Type/Rate
Aerosol Particle Size	Total Water Content
Suspended Matter	Auroral Boundary
Cloud Base Height (Derived)	Auroral Imagery
Cloud Cover/Layers	
Cloud Effective Particle Size	
Cloud Optical Depth/Transmittance	
Cloud Top Height (Derived)	
Cloud Top Pressure (Derived)	
Cloud Top Temperature	
Albedo (surface)	
Land Surface Temperature	
Normalized Difference Vegetation Index	
Snow Cover/Depth	
Vegetation Index/Surface Type	
Currents (Near Shore/Surface)*	
Freshwater Ice Edge Motion	
Ice Surface Temperature	
Littoral Sediment Transport*	
Net Heat Flux	
Ocean Color/Chlorophyll*	
Sea Ice Age/Edge Motion	
Turbidity*	

* EDRs obtained from OC channels (provided only as part of Alt 2, 3a, and 3b)

In terms of HSR, as seen in Figure 4-12 (notional data for illustration purposes only), the cost/performance of the EO imager/radiometer used in the COBRA (.8 km edge of scan HSR) lies in a relatively “flat” region (i.e., insensitive to cost variation for a given performance increment). Overall, improving the edge of scan resolution to a value half again as good as that called for in IORD-I (i.e., from .8 km to .4 km edge of scan), would imply a significant total system LCC increase (approximately 14%). On the other hand, degrading the edge of scan HSR by half again the IORD-I required value (i.e., from .8 km to 1.2 km) implies only a three to four percent decrease (savings) in anticipated LCC for the total system.

Figure 4-12. Cost/Performance Curve of EO Imager/Radiometer (Resolution)

Thus, although it is possible to construct a “lower performing” EO instrument, the fact that it would not satisfy a large majority of users’ requirements is significant. More significant perhaps is that the cost/performance sensitivity data provided from the Phase 0 contractors demonstrates that, for the relevant trade space examined, the COBRA imager/radiometer performance is not a cost driver. Cost variations appear to be within the total error of the estimate.

The cost insensitivity (particularly in terms of horizontal spatial resolution) indicates this is a marginal cost/performance trade-off area. This should be weighed against the significant contributions made by the EO imager/radiometer to the accomplishment of the users' missions.

4.3.4 X-Band Requirements Versus Availability

The Phase-0 NPOESS contractors proposed an X-Band data downlink to accommodate the increased data rate from NPOESS. The COBRA alternatives all include a notional X-Band capability (see CARD Sections 2.3.2.4 and 2.3.2.5[42]) to downlink the large amount of stored mission data. The Air Force Remote Tracking Stations do not currently have an X-Band capability. Therefore, NPOESS will be responsible for upgrading the Thule and Oakhanger tracking stations for X-Band capability. The cost of two X-Band antennas was included in the NPOESS Program Office Estimate. To ensure data availability during maintenance/downtime of the primary antenna, a second (backup) antenna may be required at each of these sites. Antenna preparation costs (including costs of antenna plus site preparation) are estimated to average about $5M per antenna in FY96 dollars. NASA is currently adding an X-Band capability to their facilities at Fairbanks, Alaska and Spitzbergen, Norway. These will be used to back-up EOS AM-1. Options exist for additional antennas to back-up PM-1 but have not been exercised to date. NOAA is also planning to add an X-band capability at Fairbanks and Wallops. As the NPOESS C^3 design evolves, these factors will be considered to arrive at the most cost effective implementation.

4.3.5 Ground Processing/Data Distribution

The IPO recognizes that the cost of duplicating certain portions of the Interface Data Processing Segment (hardware, software, interfaces) at each of the Centrals could be a cost driver. Although the IPO has not completed an exhaustive study at this time, initial data shows that the personnel charges attributed directly to the NPOESS program are minimal (i.e., if NPOESS goes away, the Centrals will still exist). Data distribution among the Centrals may be the largest contributor to NPOESS costs.

During the next phase of the “rephased NPOESS program”, the IPO will study several areas related to ground processing costs with the intention of eliminating duplication of effort to the greatest extent possible. Four of these areas include:

1) Shared Processing/Center of Excellence: Process basic EDRs only at one location.
2) Data Distribution: TDRSS, DOMSAT, Fiber Optics (ATM, SONET), Global Broadcast System (GBS)
3) Standardization of algorithms: Should all users use the same basic science algorithms?
4) Standardized IDPS hardware and software interfaces for the Centrals and also for the Tactical Terminals.

As they become available, results of these studies will be reviewed by the users to assess requirements/operational impacts, if any. Final recommendations will be available prior to Milestone I.

4.3.6 Number of Microwave Instruments

Selection of the notional microwave imaging and sounding suite was driven primarily by considerations of adequately addressing user requirements while meeting cost constraints imposed on the “baseline” system by the COBRA guidance (i.e., serving as the associated cost reference baseline). The microwave sensor suite selection was based on technical results from the NPOESS Phase 0 studies (both contractor and government) as well as broader expertise provided by U. S. Government technical consultants. The suite, in general, represents a “hybrid” of current technical approaches that are, or will be, implemented on the DMSP and POES systems. The final mix of specific sounding instruments and their actual configuration (on NPOESS) will be determined after detailed trade-off studies are performed as part of future risk reduction activities. The main issue is sizing a suite of microwave instruments that, when used in conjunction with other payloads such as the IR sounder, will adequately address the requirements within the constraints of spacecraft accommodation, cost, and technical risk.

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[42] Cost Analysis Requirements Description (CARD), 31 Jan 1996

The system described in the alternatives is a reasonable approach to addressing the requirements in question, as it meets both the system technical and cost constraints. In general, the Atmospheric Sounding area has long been recognized as one of the most complicated areas to address given the nature of traditional DoD and DOC sounding and imaging mission demands.[43] The "coregistration" of data collected by microwave and IR instrument sounders designed to address DOC missions, has in the past resulted in the use of "cross-track" microwave temperature and humidity sounders in conjunction with "cross-track" IR sounding units. DoD microwave imagery and sounding requirements (IORD-I) drive the need for data collection via "conically scanning" microwave instruments to provide refresh and all-weather imaging and sounding products to the required worst case horizontal spatial resolution. The approach adopted for costing purposes in the COBRA took all of these competing concerns into account in developing notional sensor architectures. Again, based on promising (but tentative) Phase 0 contractor and internal government study findings, some features of the cross-track microwave temperature and humidity sounders were incorporated into the conical imager/sounder in an attempt to merge pieces of the microwave suite. However, prior to the actual adoption of a specific sensor suite implementation, much more detailed technical study is required to determine the "optimal implementation", assuming one exists, for the microwave sounding capability. A detailed study of the accommodation, integration, and associated EDR product performance and cost impacts will continue prior to the selection of any "final" sensor configuration.

4.3.7 Commercial, International and Other R&D Remote Sensing System Contributions to the NPOESS Mission

A top-level survey was conducted into the potential for using commercial, international and other R&D systems that would be available in the NPOESS era.[44] In general, the survey demonstrates that while there is a wide-ranging potential for overlap in various product types, there still exists a great deal of uncertainty in the anticipated availability (e.g., quality, quantity,

[43] For example, see: "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System", Section III, Architecture/Instruments, page 18, 2 May 1994, Office of Science and Technology Policy

[44] See: "Assessment of Commercial, International and Other R&D Remote Sensing System Contributions To The NPOESS Mission", Draft, Dr. F. Sanner, Aerospace, 21 February 1996 (last revised: 31 May 1996)

and timeliness), cost, and continuity of the data products from such systems. These deficiencies would have significant impact on the users' requirements as stated in IORD-I. However, as this top-level survey indicates, the feasibility of leveraging NPOESS requirements off other systems does suggest that the cost/benefits of alternate sources for individual products should continue to be vigorously explored by IPO as an on-going activity.

4.3.8 DMSP/POES Ground Station Convergence

PA&E requested additional information relating to this subject and how it affects NPOESS.

The NPOESS C^3 Concept of Operations[45], outlined in Section 1.5 of this report and further described in Appendix B, encompasses the consolidation of the DMSP and POES Operations into the Suitland Satellite Operations Control Center (SOCC). The experience gained by the SOCC operators during Phase I, as it relates to operating both the current POES and DMSP satellites/constellations, will form a strong backbone for NPOESS operations. In particular, the knowledge and understanding of the current DMSP and POES instruments, processing, and products will smooth the transition into the NPOESS era as the NPOESS instruments will perform similar functions.

A key component being developed for Phase I of the NPOESS Convergence Operations is the Integrated Polar Acquisition and Control Subsystem (IPACS) which will merge the Command and Control functions of the NOAA NN' and the DMSP 5D2 and 5D3 satellites. PACS software will be modified to command and control DMSP. Both the POES and DMSP command and control software will run on identical computers, but will be operated on two independent sets of collocated hardware, one for DMSP and one for POES. IPACS is described in more detail in Appendix B, Section B.2.2.1.1.

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[45] Concept of Operations for Command, Control and communications (C^3) of the National Polar-Orbiting Environmental Satellite system (NPOESS) Program (C^3 CONOPS), 18 October 1995, on file in the IPO library.

4.3.9 Constellation Size Versus Mean Mission Duration

In general, the mean mission duration/design life specified for a given satellite constellation (to include both spacecraft bus and associated sensors), is one of many important design drivers which must be taken into consideration in constructing an optimal space segment architecture. Over a given period of operation (for NPOESS 10 years after IOC), the MMD/design life chosen primarily impacts areas such as the anticipated number of spacecraft that must be procured, as well as associated replenishment launches in order to adequately cover the period of operation.

The issue of the "optimal" MMD/design life for spacecraft/sensors flying in the period associated with NPOESS was extensively studied by both Phase 0 contractors, as well as during the previous Block 6 study effort. Given anticipated technology trends in both spacecraft bus and sensor lifetime, these studies demonstrated that, from a cost sensitivity perspective, the selection of an MMD on the order of 5 to 6 years would provide the greatest level of "cost savings" (i.e., fewest number of spacecraft/launch vehicles required) and would be both technically achievable and reasonable from a risk perspective.

The Phase 0 results also showed that MMDs beyond about 6 years would yield little to no cost savings. Offsetting cost increases from significantly increased satellite internal redundancy required to meet the MMD goal and increased technical risk are associated with higher MMDs. MMDs less than 5 years (particularly those less than 4 years) begin to significantly impact costs, particularly in terms of launch vehicle LCC as shown in Figure 4-13. (Data in Figure 4-13 was taken directly from the Phase 0 studies and is used here for illustration purposes only.)

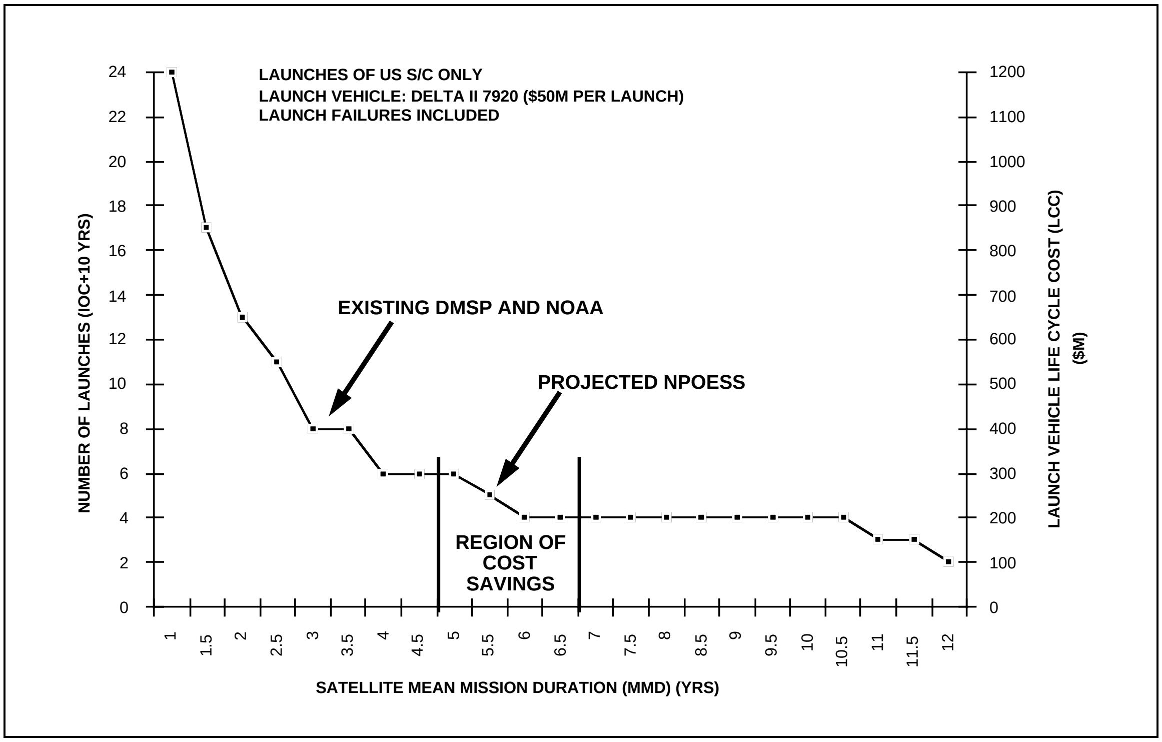

Figure 4-13. Cost Sensitivity of Launches to Satellite Mean Mission Duration

Based on these and other similar government expert/advisory inputs, an MMD of 5.5 years (suggested “design point” from the Phase 0 contractor study efforts) was adopted as a reasonable “fixed” value across the COBRA alternatives.

4.4 SUPPORTING DOCUMENTATION

Eight appendices were created to support the analysis presented in this document and they are as follows:

- Appendix A — DMSP/POES History
- Appendix B — NPOESS Command, Control and Communications (C^3) Concept of Operations
- Appendix C — DMSP and POES Sensor Complement and System Performance
- Appendix D — COBRA Alternative Descriptions
- Appendix E — EDR Definition, Use and Instrumentation
- Appendix F — Life Cycle Cost Analysis Details
- Appendix G — Operational Benefit Impact Assessments
- Appendix H — Acronyms

SECTION 5

SUMMARY OF RESULTS

Results of the cost and operational benefit analysis are provided in Table 5-1. A stop-light assessment (color ratings) is used to summarize operational benefit results for each of the five functional categories delineated. These assessments were determined by the users and should generally be interpreted as follows: “Red” was given to a functional category for an alternative if impact to one or more missions was critical (i.e., there exist severe limitations and risks or there is complete mission failure); “Yellow” was assessed if impact to one or more missions was not critical but some limitations and risks still exist; and, “Green” was assessed if all relevant missions were able to be accomplished without limitations and risks. Note that all military missions and related EDRs are considered under the single functional category Military Unique Applications while NOAA missions and related EDRs were considered under the remaining four categories. This allows the impact of unique service/agency risks and limitations to be delineated and understood. Total life cycle costs are also presented in this table. These costs include development, production, and operations and support through 2018 and are presented in FY96 dollars. Details of the analysis are provided in the body of this report and in the appendices.

The alternatives that satisfy all NPOESS IORD-I operational requirements (system-level and EDRs at the threshold level), except P^3I EDRs, are Alternatives 2, 3A and 3B. Alternative 1 does not completely satisfy either NOAA nor DoD missions. For NOAA, lack of earth radiation budget, ocean/water EDRs, and P^3I EDRs (tropospheric winds, trace gases and enhanced ozone) contribute to the risks and limitations of that alternative. For DoD missions, the lack of the ocean/water EDRs, in particular the lack of currents and ocean wave characteristics data, critically limit this alternative. Alternative 1 also fails to satisfy “system survivability”. Both Alternatives 3A and 3B, which add sensors to satisfy P^3I EDRs, are cost prohibitive in that there are no savings associated with either of these alternatives. Technical risk and accommodation issues also need to be considered with respect to Alternatives 3A and 3B. The maturity of the lidar technology which is needed for directly sensed/measured tropospheric wind profiles is an issue for Alternative 3A. Phase 0 contractor studies indicated lidar-based sensor types to be high in complexity and development risk and are not yet sufficiently demonstrated from space. For Alternative 3B, spacecraft accommodation is an issue for an enhanced ozone sensor, a CH_4/CO monitor and a CO_2 monitor. In addition, performance uncertainty is high for the CO_2 monitor.[46]

Table 5-1. Summary of Results by Functional Category

	ALT 1*	**ALT 2 (IORD-I)**	**ALT 3A**	**ALT 3B**
Life Cycle Costs (TY B$)	$7.1	$7.8	$9.1	$9.1
Operational Benefit Functional Categories				
Forecasts and Warnings (F&W)	Yellow	Yellow	Green	Yellow
Oceans and Ice (O&I)	Yellow	Green	Green	Green
Solar and Space Environment (S&SE)	Green	Green	Green	Green
Climate (C)	Yellow	Yellow+	Yellow+	Green
Military Unique Applications (MUA)	Red*	Yellow	Green	Yellow

* Although the key system-level parameter and all key EDR attributes are met by this alternative, MUA is "Red" from a system-level perspective since it fails to satisfy "system survivability" and from an oceanographic (versus meteorological) perspective due to the severe impacts (including fatalities) that could result in specific Navy missions due to lack of currents and ocean wave characteristics at threshold levels (see Appendix G).

Alternative 2 is the only alternative that completely satisfies the IORD-I requirements at the threshold level, except for P^3I EDRs, and the cost constraints placed on this study.

[46] White Paper on "Issues related to NPOESS IORD-I Potential Pre-planned Product/Process Improvements, D. Blersch, NPOESS IPO, April 1996

APPENDIX A

DMSP/POES HISTORY

This appendix provides information relevant to the history of the Department of Defense (DoD) and the Department of Commerce (DOC) polar-orbiting weather satellites prior to and including directed convergence.

A. DMSP/POES HISTORY

The United States (U. S.) Government currently operates and maintains two polar-orbiting meteorological satellite programs. The U. S. Air Force (USAF) operates the military's Defense Meteorological Satellite Program (DMSP), while the National Oceanic and Atmospheric Administration (NOAA) operates the Polar-orbiting Operational Environmental Satellite (POES) program. To reduce the costs of acquiring and operating polar-orbiting satellites, a White House Decision to integrate the two weather satellite programs into a single converged system was announced in May 1994. This decision, as part of a National Performance Review recommendation, is expected to save the U.S. Government up to an estimated $300 million in fiscal year (FY) 96-FY99 with additional savings expected after FY99. Savings will be largely determined by comparing the costs of the converged weather satellite program to planned costs of the DMSP Block 6 and NOAA O,P,Q,R Follow-On satellites which were canceled due to convergence.

A.1 DEFENSE METEOROLOGICAL SATELLITE PROGRAM

Air Force Systems Command (AFSC) assumed operational control of DMSP on 1 July 1965. Daily operations were under the direction of the Strategic Air Command (SAC), with the 4000th Support Group designated as the command and control agency for the system. Four satellites in the Block 1, 2, and 3 series were launched by September 1965, with the last Block 3 launch occurring in March 1966. The early satellites included a one-half inch video camera and two infrared systems.

Deployment of the spin-stabilized Block 4 satellites began in September 1966 and continued through 1969. These contained enhanced versions of the earlier satellites' sensors. Seven Block 4 satellites were launched.

The launch of the first Block 5A satellite in February 1970 included many new advances in vehicle dynamics. These were the first DMSP spacecraft that contained an integrated three-axis attitude control system, which kept the sensors continually pointing towards Earth. The Block 4 cameras were upgraded, with a constant-speed, scanning radiometer as the imaging sensor, in addition to other specialized sensors. The final Block 5C satellite was launched on 18 February 1976 but failed to reach orbit due to booster engine problems.

On 1 January 1973, the 4000th Support Group's official name was changed to the 4000th Aerospace Applications Group. Most of the past and future activities associated with the organization were declassified on 1 January 1974. The name was changed to the 1000th Satellite Operations Group on 1 May 1983.

The first Block 5D-1 DMSP satellite was launched 11 September 1976. However, it began to tumble, and only four hours after launch it was considered dead. After seven months of research, a solution to the tumbling problem was determined and implemented. The spacecraft returned to operational status on 1 April 1977. A total of five Block 5D-1 satellites were launched between 1976 and 1980. Block 5D-2 satellite launches began on 20 December 1982 with the launch of F-6 and will conclude with the launch of S14 (to be redesignated F15 after launch) in the late 1990s. The first Block 5D-3 launch, S15, is scheduled for mid-1996 (to be redesignated F16 after launch).

The sensors on the Block 5D satellites are technologically more advanced than the Block 5A, B, and C sensors. The primary sensor for the 5D series is the Operational Linescan System (OLS), which measures environmental data in the visible and infrared regions, to provide products such as cloud imagery and cloud top temperatures. Additional sensors measure electron/ion density, electron flux, geomagnetic fields, cloud liquid water, precipitation, ice cover, and temperature profiles. The Block 5D-3 satellites will also include sensors that measure electron density profiles and offer auroral imaging capabilities. Figure A-1 below shows the DMSP Block 5D-3 satellite.

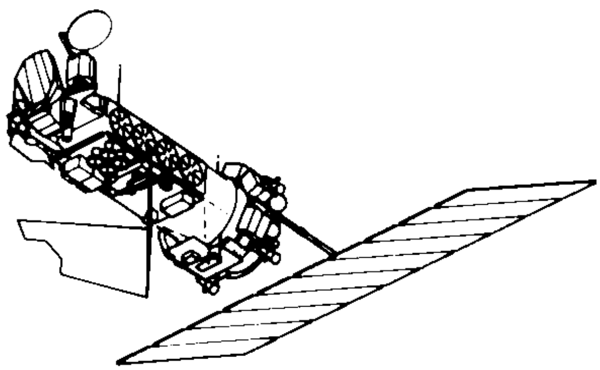

Figure A-1. DMSP Block 5D-3 Satellite

The current DMSP program requires two three-axis stabilized satellites in circular, earth-centered, sun-synchronous, near-polar orbits. At the current time, one orbit is early-morning (0530 nodal crossing time), and the other is mid-morning (0930 nodal crossing time). However, DMSP has a requirement to be able to fly at any nodal crossing time. New satellites are launched on need or anticipated need. The mean mission duration (MMD) for satellites S11-S14 is 39 months, and for S15-S20, it is 42 months.

A.2 POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE

The launch of the Television Infrared Observation Satellite (TIROS) -1 on 1 April 1960 lead the first generation of weather satellites. A total of ten TIROS satellites were launched, with TIROS-10 reaching orbit on 2 July 1965. The National Aeronautics and Space Administration (NASA) was initially in charge of TIROS operations. In April 1961, management of the civil meteorological satellite (METSAT) program was transferred to the Weather Bureau, later to the Environmental Science Services Administration (ESSA), and finally to NOAA.

The second generation of civil meteorological satellites was designated ESSA. Nine ESSA satellites were launched - from ESSA-1 on 3 February 1966 to ESSA-9 on 26 February 1969. The ESSA satellites were the first to provide continuous daily worldwide weather observations. The TIROS and ESSA satellites were all spin-stabilized spacecraft.

Improved TIROS Operational System-1 (ITOS-1), the first civil satellite with three-axis stabilization, was launched on 23 January 1970. Later satellites in the third generation were designated NOAA-1 through NOAA-5. These provided night and day imaging and global observation of the Earth's cloud cover every 12 hours. NOAA-5 was launched on 29 July 1976.

TIROS-N (launched on 13 October 1978), NOAA-A, NOAA-B, NOAA-C, and NOAA-D were the first satellites in the fourth generation. NOAA-B failed to achieve a usable orbit because of a booster engine anomaly. NOAA-D (redesignated NOAA-12 after launch) was launched in 1991. The Advanced TIROS-N (ATN) program is an extension of the TIROS program. ATN satellites contain additional payloads, such as the search and rescue package. Specifically, ATN spacecraft include advanced instruments such as the ARGOS/Data Collection System (DCS), the Advanced/Very High Resolution Radiometer (AVHRR), the High Resolution Infrared Radiation Sounder (HIRS), Microwave Sounding Unit (MSU), and Stratospheric Sounding Unit (SSU). The ATN sensors provide a variety of measurements such as cloud imagery, cloud top height, ice cover, temperature profile, water vapor profile, and earth radiance.

ATN satellites NOAA-E through NOAA-J have all been launched, with NOAA-J (redesignated NOAA-14 after launch) reaching orbit on 30 December 1994. Satellites NOAA-K through NOAA-N' represent the next series of POES ATN spacecraft. This series will incorporate a series of modest improvements with the most notable being replacement of the current radiometer (the AVHRR/2 with the AVHRR/3), and current sounding suite (the HIRS/2I, MSU, and SSU; with the HIRS/3, Advanced Microwave Sounding Unit (AMSU-A and -B). Note, for satellites N and N' the AMSU-B will be replaced by the Microwave Humidity Sounder (MHS) unit. The figure below shows the ATN satellite.

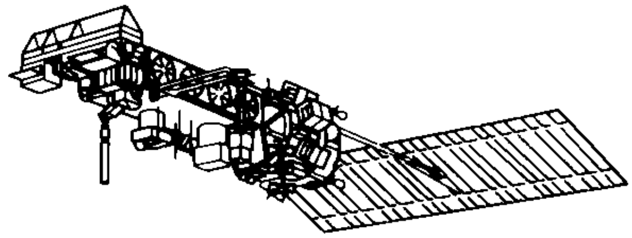

Figure A-2: Advanced TIROS-N Satellite

The current POES program requires two three-axis stabilized satellites in circular, earth-centered, sun-synchronous, polar orbits. Currently, one orbit is morning (0915), and the other is afternoon (1330). Data from the 1330 orbit are considered primary, while the 0915 orbit provides supplementary and backup coverage. New satellites are launched on need. The MMD for the POES spacecraft is 47 months, and the MMD for the sensors is 50 months.

A.3 CONVERGENCE

The DoD precursor program to NPOESS was the DMSP Block 6. Upon completion of Concept Studies started in 1988, two risk reduction contracts were awarded in July 1991 to define a military next-generation satellite system (including the space, command, control and communications (C^3), and user segments) to provide meteorological, oceanographic, and solar-environmental support to all DoD users. The purpose of the risk reduction effort was to develop preliminary system designs and perform key demonstrations for the baseline system. Additionally, the U. S. Navy intended to fund an option to perform risk reduction on Navy specific sensors and develop plans for upgrading Navy ground and ship-based terminals for Block 6 capabilities. The U. S. Army as well as other government agencies planned to identify agency specific requirements for risk reduction which would have been funded as options.

The comparable DOC program was the NOAA Follow-On Program, also known as the O,P,Q acquisition. Phase A (concept exploration study phase) for these satellites was initiated in 1991. Some of the initial design characteristics were common interfaces with the European Meteorological Operational (METOP) program, growth room to accommodate selected, proven Earth Observing System (EOS) instruments, and a three year design life. Due primarily to the preliminary cost estimates, Congress redirected the O,P,Q program to reduce its size, scope, and cost. To comply with the Congressional direction, NOAA developed and submitted a revised follow-on polar satellite budget that included a descoped O,P,Q program, plus the NOAA N and N' satellites. Changes to the O,P,Q program included changing to a smaller bus, replacing the microwave temperature sounder (MTS) by an AMSU-A and basing the infrared sounder on the Interferometer Thermal Sounder (ITS) design instead of the more complex Advanced Infrared Sounder (AIRS). Since the O,P,Q redirection caused a delay in follow-on mission readiness, Congress authorized N and N' as gap fillers. They are basically carbon copies of the NOAA K,L,M design. A contract for N and N' was awarded in December 1994.

In February 1993, the House Committee on Science, Space, and Technology requested DoD and NOAA to begin looking at opportunities to integrate the DMSP and POES programs and investigate the use of technologies developed by the EOS program. A tri-agency study with DoD, NOAA, and NASA was initiated in June 1993 at the request of Congress and later directed by the National Performance Review. During this time, the DMSP Block 6 Risk Reduction efforts were redirected to focus on convergence trade-off opportunities. The result of this tri-agency study was an agreement to develop a converged operational polar-orbiting environmental satellite system with a transition period beginning in the late 1990s, leading to a fully converged system by the mid 2000s. This agreement was formalized by the Office of Science and Technology Policy (OSTP) with the Implementation Plan for a Converged Polar-orbiting Environmental Satellite System, 2 May 94. On May 5, 1994, a Presidential Decision Directive/National Science and Technology Council (PDD/NSTC)-2 was signed directing DoD and DOC to converge their independent operational polar-orbiting environmental satellite systems into a single, integrated system. A tri-agency Memorandum of Agreement (MOA) specifies the roles and responsibilities and agreements between the agencies. The NPOESS program will acquire the necessary space, C^3, launch, and interface data processor assets to operate and support the program for at least 10 years after Initial Operating Capability (IOC).

The Tri-Agency Implementation Plan (dated 2 May 94) authorizes NPOESS to streamline the DoD 5000 acquisition process. The NPOESS program plans to have two tailored program milestones and a series of three event-driven phases. A 31 Jan 95 Acquisition Memorandum signed by the Under Secretary of Defense (Acquisition and Technology (USD(A&T)) placed the program into Phase 0, concept exploration, thus eliminating the need for a formal Milestone 0 review. The NPOESS future acquisition phases will be Program Definition and Risk Reduction (PDRR), and Engineering and Manufacturing Development (EMD)/Production/O&S. These phases will be initiated by two tailored milestones: Approval to Enter Program Definition and Risk Reduction (Milestone I) and Approval to Enter Development (Milestone II). The approach is to procure all the required satellites under Research, Development, Test, and Evaluation (RDT&E) funding during the EMD phase, thus a Milestone III decision is not needed. Four to six satellites will need to be delivered or in production prior to the launch of the first satellite in order to meet program availability requirements/synchronization/timing goals. It is not cost effective to go into a Production phase with a buy of one to three satellites.

The objective of this acquisition strategy is to reduce the cost, schedule, and technical risks of developing and fielding a NPOESS. The DMSP Block 6 and NOAA O,P,Q Concept Exploration studies have resulted in hundreds of technical trade-offs which have been synthesized into a draft system specification. The PDRR phase is designed to insure that system development and planning, as well as technical risk mitigation, is completed to support EMD.

A.4 TRANSITION

On 5 May 94, the President directed the DOC and DoD to converge their current polar-orbiting operational environmental satellite systems into a single program. The MOA between DOC, DoD, and NASA directs the NPOESS Integrated Program Office (IPO) to develop a plan to transfer responsibility for operating the on-orbit assets of the DMSP program to the IPO as soon as practical. Acquisition of the remaining DMSP satellites remains the responsibility of Air Force Materiel Command Space and Missile Center (AFMC/SMC). Air Force Space Command (AFSPC)/DRF and AFMC/SMC/CI concurred with the recommendation of the IPO/Associate Director of Operations to acquire an Integrated Polar Acquisition and Control System (IPACS) on 30 June 95 (Decision Memo). The transition phase will significantly reduce the risk associated with merged DMSP/POES operations and lay the ground work necessary for future NPOESS operations, both during and after the flyout of the current systems. Additional details on the Operational Concept during the transition phase and on IPACS are presented in Appendix B.

DMSP is currently operated from two control nodes: the Multi-Purpose Satellite Operations Center (MPSOC) at Offutt Air Force Base (AFB), NE, by 6 Satellite Operations Squadron (SOPS); and the Fairchild Satellite Operations Center (FSOC) at Fairchild AFB, WA, by Detachment 1, 6 SOPS. MPSOC is the primary center for normal operations, mission planning, engineering, launch and early orbit support, and anomaly resolution. FSOC conducts bent pipe tracking station operations and is a 72 hour warm backup. Prior to this round of Convergence activities, AFSPC had decided to close both of these satellite operations centers and consolidate DMSP operations at Falcon AFB, CO. Milestones for this effort are shown below.

MAJOR MILESTONES (pre-NPOESS)	**end of**
a. Vandenberg Upgrade	1st quarter FY97
b. FSOC Ceases Operations	2nd quarter FY97
c. FSOC Closes	4th quarter FY97
d. Suitland DMSP IOC	3rd quarter FY98
e. MPSOC Ceases Operations	3rd quarter FY98

APPENDIX B

NPOESS COMMAND, CONTROL, AND COMMUNICATIONS (C^3) CONCEPT OF OPERATIONS

This appendix provides details regarding the Command, Control, and Communications (C^3) Concept of Operations[1] of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) with emphasis on the Transitional Defense Meteorological Satellite Program (DMSP) and Polar-orbiting Operational Environmental Satellite (POES) Operations (Phase I), described in Section B.2. This phase will last for approximately seven years from 1997 to 2004. A key element of this phase is the Integrated Polar Acquisition and Control Subsystem (IPACS) which is described in Section B.2.2.1.1.

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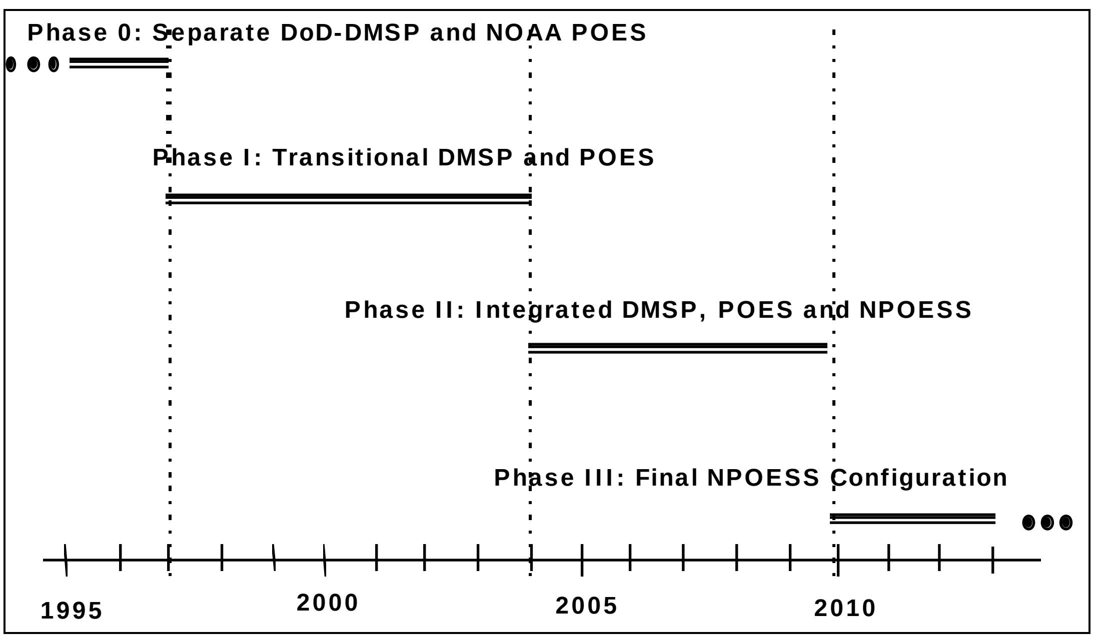
[1] Concept of Operations for Command, Control and Communications (C^3) of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Program (C^3 CONOPS), 18 October 1995, available in the IPO Library.

B. NPOESS C³ CONCEPT OF OPERATIONS

B.1 OVERVIEW OF PHASES OF C³ CONVERGENCE OPERATIONS

The NPOESS C³ Concept of Operations (CONOPS) will cover four phases of polar satellite operations between now and approximately 2010, at which time there will be a full up NPOESS constellation consisting of two United States (U. S.) and one Meteorological Operational (METOP) satellite. These phases cover not only the period of operation of the new NPOESS (circa 2004+), but also transitional periods, commencing with the transfer of operations of the Department of Defense (DoD) DMSP and National Oceanic and Atmospheric Administration (NOAA) POES to the Integrated Program Office (IPO) (circa 1997), and the flights of METOP satellites by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) commencing around the year 2000. Figure 1-3 shows the timeline[2] for each phase. Because of uncertainties associated with exact dates of each phase, these dates are for reference only. The phases are described below.



Note: Dates are notional

Figure B-1. Phases of NPOESS Convergence Operations

[2] "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System", Section III, Ground Support, 2 May 1994, Office of Science and Technology Policy

B.1.1 Phase 0, Separate DoD-DMSP AND NOAA-POES Operations (Present to circa 1997)

Operations, control, launch, etc., of the present DMSP and NOAA POES will remain under the auspices of DoD and Department of Commerce (DOC) respectively as they currently exist. No new C^3 CONOPS will be implemented during this Phase, however, the Associate Director of Operations (ADO) will work with DoD and DOC counterparts during this Phase to develop a C^3 Implementation Plan leading to Phase I.

B.1.2 Phase I, Transitional DMSP and POES Operations (Circa 1997 to 2004)

This Phase applies when the IPO is fully capable of controlling the DMSP satellites from the Suitland Satellite Operations Control Center (SOCC) and continues up to the earliest possible launch of the first NPOESS (circa 2004). During this period, the IPO will be responsible for operating all DMSP and POES satellites, and providing blind-orbit support and Telemetry, Tracking and Commanding (TT&C) backup to the METOP satellites in accordance with international agreement(s) in effect at that time. The Suitland SOCC will be the primary operations center for both DMSP and POES, and through its Command and Data Acquisition (CDA) stations, will provide blind orbit services and TT&C backup for EUMETSAT. A backup Satellite Operations Center (SOC) will be established at Falcon Air Force Base (AFB), Colorado, as a DMSP backup only. NOAA will continue to provide backup to the POES and METOP satellites (in accordance with international agreement(s) in effect at that time) through its CDA stations. Transition to NOAA operation for Phase I will permit the phase out of the dedicated tracking station at Fairchild AFB and the Multi-purpose Satellite Operations Center (MPSOC) at Offutt AFB.

B.1.3 Phase II, Integrated DMSP, POES and NPOESS Operations (Circa 2004 to 2010)

During this Phase, the IPO will launch and operate the new NPOESS as well as continue to operate the remaining DMSP and POES spacecraft, and will provide blind-orbit support and TT&C backup for the METOP series of spacecraft in accordance with international agreement(s) in effect at that time. The Suitland SOCC will be primary for DMSP, POES, and NPOESS operations. Division of TT&C, data relay, and processing activities between METOP facilities and the NPOESS SOCC have not yet been defined. The Falcon AFB SOC will be a backup only for DMSP and NPOESS operations and METOP support (starting with METOP-3, details as yet undefined). NOAA will continue to provide backup for POES and METOP 1 and 2 satellites through its CDA stations in accordance with international agreement(s) in effect at that time.

B.1.4 Phase III, Final NPOESS Configuration Operations (Circa 2010 and beyond)

Phase III begins when there are no longer any operational spacecraft remaining from the DMSP and POES series, and continues for the life of the NPOESS Program. The Suitland SOCC will be primary for NPOESS, METOP (in accordance with international agreement(s) in effect at that time), and any “residual” POES or DMSP. The backup SOC at Falcon AFB will only be capable of operating NPOESS and “residual” DMSP satellites, and providing METOP-3 support.

B.2 PHASE I DETAILS, TRANSITIONAL DMSP AND POES OPERATIONS

Phase I begins when the IPO is capable of operating DMSP satellites through the SOCC. During Phase I, POES operations will be integrated with DMSP operations under the responsibility of the IPO. Late in this phase (circa 2002), the IPO will commence provision of blind-orbit support and back-up TT&C to the EUMETSAT series of METOP satellites in accordance with international agreements in effect at that time. The Phase I C^3 CONOPS will no longer apply once the first NPOESS spacecraft is launched.

B.2.1 Space Segment

The space segment will consist of all on-orbit DMSP and POES satellites. Nominally this will consist of two operational DMSP satellites, two operational POES satellites and any residual satellites available. Although some services may be provided to METOP through NOAA, the METOP satellites are not considered part of the NPOESS Space Segment in Phase I. Residual satellites will be maintained on-orbit for supplemental collection capability, operational back-up, test and evaluation, etc. DMSP and POES satellites will continue to be launched based on operational need.

B.2.2 Command, Control and Communications Segment

This segment will consist of the ground-based elements which provide all functions necessary to maintain the state of health and to recover and distribute the data collected from the space segment to central and real-time users. These elements include SOCs, communication links and associated antennas.

B.2.2.1 Satellite Operations Centers

The SOCs perform the functions necessary for the operation of POES and DMSP, and support to METOP satellites in accordance with international agreement(s) in effect at that time. The IPO will be responsible for the full operation of DMSP and POES and back-up to METOP under the direction of the IPO's ADO. The IPO will conduct operations from NOAA's SOCC at Suitland, MD. A backup SOC for DMSP operations will be located at Falcon AFB, Colorado. The Falcon AFB SOC will be minimally manned, but fully capable of performing all C^3 functions for the DMSP (except Launch and Early Orbit (LEO) support) as a backup to the Suitland SOCC. Operational C^3 backup for POES will be provided by the DOC/NOAA CDA sites at Fairbanks, Alaska and Wallops Island, Virginia.

IPACS. A contract to develop an IPACS will be awarded in Fiscal Year (FY) 96 with a completion date of late FY97. The integration of SOCC and the MPSOC satellite control center functions at the NOAA SOCC, to operate in conjunction with designated tracking stations, will be accomplished via the IPACS. IPACS will retain all of the functional characteristics of the existing NOAA operational Polar Acquisition and Control Subsystem (PACS) and incorporate those functions unique to command and control operations for the polar-orbiting DMSP 5D-2 and 5D-3 satellites. DMSP ground system devices will be relocated to the SOCC to provide the data handling for telemetry processing, voice and data encryption, command generation and encryption, and interfaces to government furnished equipment and communications facilities necessary to operate with the Air Force Satellite Control Network (AFSCN). IPACS will provide current technology Telemetry and Command Subsystem (TCS) processors, compatible with the PACS applications software, which will provide central processing for IPACS operations. Specific operations to be performed by IPACS at the SOCC during the launch and sustained mission operations phases include:

- Generation of satellite stored command loads
- Initiation of command sequences to the satellite
- Verification of error free receipt of commands by the satellite
- Providing encrypted commands for transmission via the AFSCN for LEO support, satellite emergency operation, and sustained mission operations
- Monitoring critical satellite telemetry in real-time and playback modes
- Monitoring payload instrument health and safety
- Maintaining satellite telemetry databases
- Generating the daily satellite on-board processor Stored Command Table, Operational Linescan System (OLS), mission sensor configuration, tape recorder management, and ephemeris load files
- Analyzing satellite performance
- Scheduling, monitoring, and controlling SOCC and Automated Remote Tracking Station (ARTS) equipment configuration and status
- Generating SOCC and ARTS configuration schedule files
- Generating a history file of satellite telemetry; time tagged satellite, SOCC, and ARTS events, and commanding history files
- Maintaining databases of satellite parameters, equipment status, and communications records

Additional details of the IPACS performance specifications may be found in the IPACS solicitation, NOAA No. 52-DDNE-6-00029. (This document is not appended.)

B.2.2.2 Communications Element

Communication links are those elements of the C^3 segment which provide the required connectivity to support command and control functions and primary data distribution services for the POES and DMSP space segments. The transitional DMSP program will continue to rely on domestic satellites (DOMSAT) and other established communication links to perform its mission. Similarly, the communications element for the POES program will not change during Phase I. Additional connectivity will be established to ensure continuous, high volume interaction between the DMSP computers at the Suitland SOC and the Falcon AFB SOC.

B.2.2.3 Antenna Element

The antenna element consists of the ground based equipment necessary to receive stored mission data and telemetry (stored and real-time), as well as transmit up-link commands throughout the program segments. DMSP operations will utilize the AFSCN Remote Tracking Stations (RTS). The AFSCN is utilized by many different government satellite programs and DMSP will share time with these programs. DMSP will continue to have the same priority within the AFSCN during Phase I as it currently has under Phase 0. The AFSCN is operated and maintained separately from the POES, DMSP, and NPOESS programs. The sites below with an asterisk are current or projected DMSP enhanced ARTS and are the only ones currently capable of performing Mission Data Recovery (MDR) for DMSP. Vandenberg currently does not have this capability but will be upgraded before the Fairchild Satellite Operations Center (FSOC) is closed. All sites listed below are capable of providing DMSP TT&C services.

* Thule, Greenland
* New Boston, New Hampshire
* Kaena Point, Hawaii
* Vandenberg AFB, California
Falcon AFB, Colorado

Anderson AFB, Guam

Oakhanger, United Kingdom

Mahe, Seychelles Islands

Diego Garcia Island, United Kingdom Indian Ocean Territory

POES and METOP, in accordance with international agreement(s) in effect at that time, will use the DOC/NOAA CDAs. Communication with the POES and METOP satellites is performed through the CDA sites at Fairbanks, Alaska and Wallops Island, Virginia, with a ground site at Lannion, France providing blind-orbit POES housekeeping (TT&C) support. In addition to providing communications and data retrieval for the POES system, the CDA sites can also perform most C^3 functions in the event of data line or communications failure at the Suitland SOCC. The CDAs can provide POES backup support for the following functions: satellite command and control, mission planning, antenna scheduling, and relay of data to central users.

B.2.3 User Segment During Phase I

B.2.3.1 Central Users

Central users are those processing centers within the U. S. Government that receive, process, and analyze DMSP and/or POES data in combination with other data sources to generate weather, space, and environmental products. Central users during Phase I will remain as they currently exist. The central users will retain responsibility for software development and maintenance to support their processing needs. The DoD central users include: the Air Force Global Weather Central (AFGWC) at Offutt AFB, Nebraska; the 50th Weather Squadron (50 WS), formerly the Air Force Space Forecast Center (AFSFC), at Falcon AFB, Colorado; the Naval Oceanographic Office (NAVOCEANO) at Bay St. Louis, Missouri; and the Fleet Numerical Meteorology and Oceanography Center (FNMOC) at Monterey, California. The National Environmental Satellite, Data, and Information Service (NESDIS) is the DOC/NOAA central user and will continue to provide data from its Suitland, Maryland facility to U. S. and international data centers through its established interfaces.

B.2.3.2 Real-Time Users

Real-time users are those users that receive DMSP and POES data as the satellites pass over that ground station. Available real-time data transmissions from DMSP and POES include:

- DMSP Real-Time Data (RTD) and Real-Time Data Smooth (RDS)
- POES High Resolution Picture Transmission (HRPT) and Automated Picture Transmission (APT)

During Phase I, real-time users will continue to receive data as they currently do. Any pertinent changes to POES or DMSP operations that may affect real-time data users will be distributed to them via service messages.

B.2.4 Initial Operational Capability

Phase I Initial Operational Capability (IOC) will be attained when the IPO is able to command and control the on-orbit DMSP satellites from the Suitland SOCC. The Suitland SOCC will, in addition, continue to operate the POES satellites. During the period between Phase I IOC and Final Operational Capability (FOC), the DMSP MPSOC at Offutt AFB, Nebraska, will perform DMSP functions that Suitland SOCC is not able to perform. Once the Suitland SOCC can perform all operational functions for DMSP described in Section B.2.5, MPSOC may be deactivated as planned by the USAF. AFSPC shall certify and document Suitland SOCC's ability to perform DMSP operations prior to Satellite Control Authority being transferred to the IPO.

B.2.5 Operations During Phase I

B.2.5.1 Satellite Command and Control

Satellite command and control consists of state of health verification, satellite navigation and orbit determination, MDR, and other satellite commanding necessary to operate and maintain on-orbit satellites. Satellite command and control will routinely be exercised through the Suitland SOCC. The responsibility for DMSP and POES operations can be passed to the respective backup facilities if the Suitland SOCC becomes incapable of performing its function. The

IPO/ADO, in coordination with the 50th Space Wing at Falcon AFB, may direct operational control for all or part of DMSP to be shifted to the Falcon AFB SOC for reasons both agencies feel necessary. Similarly, the IPO/ADO may direct operational control of all or part of the POES system to be transferred to the CDAs.

B.2.5.2 Mission Planning

Mission planning encompasses all actions necessary to schedule, program, and manage operations for each satellite. During Phase I, the Suitland SOCC will generate and disseminate all information needed for operation of the DMSP and POES satellites. The planning functions currently performed at the MPSOC at Offutt AFB for DMSP will be performed by the Suitland SOCC or the Falcon AFB SOC, as appropriate. Schedules will be generated based on data collection and playback requirements of the central and real-time users. The IPO will establish procedures to ensure the C^3 segment is responsive to users' special data and operational requirements.

B.2.5.3 Antenna Resource Scheduling

The two SOCs will have the capability to interface with the AFSCN to request and obtain support for tracking and mission data recovery from the DMSP satellites. This function involves scheduling AFSCN antenna resources in support of satellite command and control and MDR. Scheduling will be accomplished by interfacing to the AFSCN Resource Scheduling Element. Suitland SOCC will continue to coordinate CDA support for POES tracking and data collection.

B.2.5.4 Launch and Early Orbit Operations

This function involves the unique satellite command, control, tracking, and anomaly resolution required when a satellite is initially deployed. The Suitland SOCC will perform LEO operations for all new POES satellites. DMSP System Program Office (SPO) personnel, in accordance with provisions in the memorandum of agreement (MOA) between the IPO and SMC/CI, will direct/manage LEO operations for new DMSP spacecraft from the Suitland SOCC. Launch deployment authority will be addressed in the MOA. Resources must be carefully scheduled to avoid launch support conflicts or interruptions to C^3 requirements of operational satellites. DMSP and POES spacecraft will attain operational status when the primary mission sensors are functioning nominally and mission data are being received by the central users as required. At that time, the new satellite will be turned over to control of the IPO for operations. The Falcon AFB SOC will not perform this LEO function for either satellite.

B.2.5.5 Anomaly Resolution

Satellites which are experiencing unique or unusual indications require anomaly resolution. Anomaly resolution refers to the non-routine procedures necessary to return a satellite to normal status. Anomaly resolution for both DMSP and POES will normally be performed at the Suitland SOCC, however, this function can be performed from the Falcon SOC for DMSP satellites. The IPO operations staff, in conjunction with Suitland SOCC and DMSP SPO, will adapt current POES and DMSP anomaly resolution procedures for use during all phases of convergence.

B.2.5.6 Data Access

Access to POES data will remain unlimited throughout the duration of this phase. Access to DMSP data, however, is restricted. Data denial is accomplished by DMSP using data encryption methods. Transmissions emanating from the DMSP satellites are encrypted to limit access to the collected data and command and control of the satellite. Data retrievals via the Spacecraft Telemetry, RTD, RDS and playback and record transmissions can only be accomplished using the correct National Security Agency approved cryptographic devices. DMSP data encryption capabilities will continue throughout all phases of convergence.

B.2.5.7 Relay of Data to Central Users

This function involves the communication of mission payload data to central data processing facilities. These facilities then process the data for use in generating forecasts and analysis of environmental parameters. Received data and the products generated by the central users can then be transmitted to customers around the world. During Phase I, any changes to the communication of DMSP and POES data to central users will be transparent to the users. Only the command and control functions will be altered. Central users will use the new C^3 structure to request data reships, change data requirements, report problems, etc. Central users that have direct access to a DMSP DOMSAT station (currently Air Force Global Weather Center and Fleet Numerical Meteorology and Oceanography Center) will continue to receive DMSP mission sensor data through that path.

B.2.5.8 Spacecraft and Sensor Engineering

The continuous monitoring of spacecraft systems, analysis of system status and performance, sensor calibration, and recommendation of command routines needed to maintain the spacecraft in peak health and to recover from spacecraft anomalies will be conducted at the SOC. Sensor calibration is done in close coordination with the central data processing facilities.

B.2.5.9 Operational Reporting

All reports requested or required in regard to the health, status, and daily operations of the DMSP and/or POES satellites will become the responsibility of the IPO when the IPO assumes responsibility for daily operations of a particular constellation or satellite. The content, timing, and frequency of such reports will be mutually agreed to by the IPO and the requesting agency, and documented in memorandums of understanding or agreement.

APPENDIX C

DMSP AND POES SENSOR COMPLEMENT AND SYSTEM PERFORMANCE

DMSP Block 5D3 and NOAA K-N' satellites are the predecessors to NPOESS. The sensors utilized by each system are captured in Table C-1. The capabilities for the systems, first as separate systems, and then as a combined system, are shown in a stop-light chart in Table C-2. DMSP Block 6 and NOAA O,P,Q,R plus METOP satellites were to be the follow-on systems that will be replaced by NPOESS (plus METOP). The sensors utilized by each system are captured in Table C-3. The capabilities for the systems, first as separate systems, and then as a combined system, are shown in a stop-light chart in Table C-4. The stop-light capability assessments shown in Tables C-2 and C-4 are in comparison to IORD-I requirements. References for these tables appear at the end of each table.

Table C-1. DMSP Block 5D3 and NOAA K-N’ (plus METOP) Descriptions

DMSP Block 5D3

A total of six (6) spacecraft will be acquired under the Block 5D3 Program (it is expected that the first three will be launched on Titan II vehicles and the last three will be launched on the planned Extended Expendable Launch Vehicle (EELV)). The mission payload for each satellite is identical and includes the following:

Sensor	Sensor Description
Operational Linescan System	3 channel imager (.4-.8 km visible, 1.5 km infrared, 3.7 km LL)
SSMIS	Conical microwave imager/sounder
Space Environment Sensors	SSIES, SSULI, SSUSI, SSM, SSJ/5

NOAA K-N’ (including METOP)

A total of five (5) spacecraft and seven (7) payload sets were planned to be acquired under the NOAA K-N’ Program (NOAA K, L, M are planned for Titan II launch vehicles while N and N’ are planned for Delta II launch vehicles). As discussed in Appendix B, NOAA N and N’ will be launched in an afternoon orbit and beginning with METOP-1, EUMETSAT assumes responsibility for the morning orbit. METOP 1 and 2 get government furnished equipment (GFE) U.S. payloads. The mission payload for each satellite is identical and includes the following:

Sensor	Sensor Description
Advanced Very High Resolution Radiometer/3 [1]	5-6 channel radiometer
High Resolution Infrared Sounder/3 [1]	Cross-track infrared sounder - filter wheel
Atmospheric Microwave Sounding Unit -A [1]	Cross-track microwave temperature sounder
Atmospheric Microwave Sounding Unit -B [1]	Cross-track microwave humidity sounder
Space Environment Sensors [1]	TED, MEPED
ARGOS/Data Collection System [1], [2]	Data collection System
Solar Backscatter Ultraviolet Radiometer/2	ozone profiler - nadir view
Search and Rescue Satellite Aided Tracking [1], [2]	Search and rescue

Notes: [1] Will also fly on METOP-1/2 in the 0930 orbit;
[2] Provided by foreign governments to fly on NN’

Table C-2. System Capability Assessment
(DMSP 5D3, NOAA K-N' Plus METOP)
(last revised 9 June 1996)

Assumptions and Caveats: This analysis is a first-order assessment of the overall relative capabilities of the systems listed. System performance relative to each EDR in question was evaluated against the NPOESS IORD-I requirements. Data on individual systems under review was obtained from various sources and therefore is a "mix" of documented performance values (although not always validated), individuals within DoD, DOC, and NASA who provided "expert opinions" on specific performance questions, and extrapolations/projections based on the relative performance of the various sensors under discussion. Current systems (5D3/K-N') performance, judged relative to IORD-I, is tied primarily to anticipated capability during the projected time of operation.

CAUTION should be used when evaluating the color-code data assessments. Due to the number of factors involved, a large "subjective element" is inherent in any assessment of the systems under discussion. All questions regarding this assessment or issues it may raise should be referred to the NPOESS IPO for detailed discussion/resolution. IPO POC: Mr. Donald Blersch (301) 427-2077 (x 165).

IORD-I (Dec '95)[1]	**DMSP 5D3** (2 orbit planes)	**NOAA K-N'** (2 orbit planes: 1 NOAA; 1 METOP)	**5D3&K-N'** (4 orbit planes: 2 Block 5D3; 1 NOAA; 1 METOP)
Key Parameters (6)			
Vertical Moisture Profile	Orange	Yellow[2]	Yellow
Measurement Accuracy	*Yellow*	*Green*	*Green*
Vertical Temperature Profile	Orange	Yellow[3]	Yellow
Measurement Accuracy	*Yellow*	*Green*	*Green*
Imagery	Yellow[4]	Yellow[5]	Yellow
Horizontal Resolution	*Yellow*	*Orange*	*Yellow*
Refresh	*Yellow*	*Yellow*	*Green*[6]
Sea Surface Temperature	Orange	Yellow[7]	Yellow
Horizontal Resolution	*Orange*[8]	*Green*	*Green*
Measurement Accuracy	*Orange*[9]	*Green*	*Green*
Sea Surface Winds (Sp&Dir)	Orange[10]	Red	Orange
Measurement Accuracy (Sp)	*Green*	*Red*	*Green*
Soil Moisture (Surface)	Orange	Red	Orange
Sensing Depth	*Green*	*Red*	*Green*

Table C-2. (continued)

IORD-I (Dec '95)	**DMSP 5D3**	**NOAA K-N'**	**5D3&K-N'**
Atmospheric Parameters (8)			
Aerosol Optical Thickness	Red	Yellow[11]	Yellow
Aerosol Particle Size	Red	Yellow	Yellow
Ozone Total Column/Profile	Red	Yellow	Yellow
Precipitable Water	Yellow	Yellow	Yellow
Precipitation Type/Rate	Yellow	Yellow	Yellow
Pressure (Surface/Profile)	Orange	Yellow	Yellow
Suspended Matter	Orange	Yellow	Yellow
Total Water Content	Yellow	Yellow	Yellow
Cloud Parameters (9)			
Cloud Base Height	Red[12]	Red[13]	Red[14]
Cloud Cover/Layers	Yellow	Yellow	Yellow
Cloud Effective Particle Size	Red	Yellow	Yellow
Cloud Ice Water Path	Yellow	Yellow	Yellow
Cloud Liquid Water	Yellow	Yellow	Yellow
Cloud Optical Depth/Transmittance	Red	Yellow	Yellow
Cloud Top Height	Orange	Yellow	Yellow
Cloud Top Pressure	Orange	Yellow	Yellow
Cloud Top Temperature	Orange	Yellow	Yellow
ERB Parameters (6)			
Albedo (Surface)	Orange	Yellow	Yellow
Dwn Longwave Rad (Surf)	Red	Yellow	Yellow
Insolation	Red	Yellow	Yellow
Net Shortwave Rad (TOA)	Red	Yellow	Yellow
Solar Irradiance	Red	Red	Red
Total Longwave Rad (TOA)	Red	Yellow	Yellow
Land Parameters (4)			
Land Surface Temperature	Orange	Yellow	Yellow
Normalized Diff Veg Index	Red	Yellow	Yellow
Snow Cover/Depth	Orange	Yellow	Yellow
Vegetation/Surface Type	Yellow	Yellow	Yellow

Table C-2. (continued)

IORD-I (Dec '95)	**DMSP 5D3**	**NOAA K-N'**	**5D3&K-N'**
Ocean/Water Parameters (11)			
Currents (Nr Shore & Surface)	Red	Orange[15]	Orange
Fresh Water Ice Edge Motion	Yellow	Orange	Yellow
Ice Surface Temperature	Orange	Yellow	Yellow
Littoral Sediment Transport	Red	Red	Red[16]
Net Heat Flux	Orange	Yellow	Yellow
Ocean Color/Chlorophyll	Red	Red	Red
Ocean Wave Characteristics	Red	Red	Red
Sea Ice Age & Edge Motion	Yellow	Orange	Yellow
Sea Surface Height/Topography	Red	Red	Red
Surface Wind Stress	Orange[17]	Red	Orange
Turbidity	Red	Red[18]	Red
SES Parameters (17)			
Auroral Boundary	Orange	Red	Orange
Total Auroral Energy Deposit	Orange	Red	Orange
Auroral Imagery	Orange	Red	Orange
Electric Field	Orange	Red	Orange
Elect Den Profile/Iono Spec	Orange	Red	Orange
Geomagnetic Field	Orange	Red	Orange
In-situ Ion Drift Velocity	Orange	Red	Orange
In-situ Plasma Density	Orange	Orange	Orange
In-situ Plasma Fluctuations	Red	Orange	Orange
In-situ Plasma Temperature	Orange	Orange	Orange
Ionospheric Scintillation	Orange	Red	Orange
Neutral Den Profile/Atmos Spec	Orange	Red	Orange
Rad Belt/Low Energy Sol Part	Red	Orange	Orange
Solar Gal Cosmic Ray Particles	Red	Orange	Orange
Solar EUV Flux	Red	Red	Red
Supra Thermal/Auroral Particle	Orange	Red	Orange
Upper Atmosphere Airglow	Orange	Red	Orange

Table C-2. (concluded)

IORD-I (Dec '95)	**DMSP 5D3**	**NOAA K-N'**	**5D3&K-N'**
P[3]I EDRs (9)			
Tropospheric Winds	Red[19]	Red	Red
Ozone Profile - High Resolution	Red	Red	Red
Methane (CH_4) Column	Red	Red	Red
Carbon Monoxide (CO) Column	Red	Red	Red
Carbon Dioxide (CO_2) Column	Red	Red	Red
Optical Backgrounds	Red[20]	Red	Red
Bathymetry (DpOc&NrSh)	Red	Red	Red
Bioluminescence	Red	Red	Red
Salinity	Red	Red	Red
System Parameters (12)			
Data Access (Key)	*Green*	*Orange*	*Yellow*
Data Availability	Green	Green	Green
Autonomous Operations	Yellow	Orange	Yellow
Stored High Resolution Data	Yellow	Orange	Yellow
Surface Data Collection	Red	Green	Green
Orbital Characteristics	Yellow	Orange	Yellow
System Survivability	Yellow	Red	Orange
Search and Rescue	Red	Green	Green
Compatibility	Orange	Yellow	Yellow
Space Debris Minimization	Red	Red	Red
Space Environ Constell Char	Yellow	Yellow	Yellow
Geolocation of Data	Yellow	Orange	Yellow

KEY: **Red**-No Capability; **Orange**-Sig Below Threshold; **Yellow**-Below Threshold; **Green**-Meets Threshold; **Blue**-Exceeds Threshold.

ENDNOTES:

[1] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).

[2] Falls somewhat below sampling interval req.

[3] Falls somewhat below sampling interval req.

[4] Fails multispectral req; falls somewhat short of some HSR req (global nadir, LL), also provides no quantitative data for other EDRs per EDR req. description lead-in paragraph.

[5] Fails HSR requirements (regional, global worst case, no night visible), does provide multispectral, quantitative data for other EDRs per EDR lead-in paragraph.

[6] Unevenly spaced nodal crossing times for the "four satellite" constellation assumed to yield refresh roughly comparable to that obtained with an evenly spaced nodal crossing time "3 satellite" constellation.

[7] Current capability falls somewhat short of EDR thresholds in several categories - global nadir, regional worst case, regional mapping accuracy, and measurement range.

[8] Current SSMI HSR is on the order of 70km. SSMI SST product exists, however NOAA - AVHRR derived product is relied upon by DOC and DoD as part of the USG's Shared Processing Program.

[9] Current SSMI MA is on the order of 2K. SSMI SST product exists, however NOAA - AVHRR derived product is relied upon by DOC and DoD as part of the USG's Shared Processing Program.

[10] Fails to address EDR in several respects: HR, mapping accuracy, no wind direction information.

[11] Although rated "yellow", quoted AVHRR performance in the K-N' era is expected to fall within or approach the threshold demands required in IORD-I for this parameter.

[12] HSR Imagery of marginal utility without coincident HR IR-type sounding and radiometric data.

[13] IR-type soundings and radiometric data potentially useful, however "low resolution" AVHRR-type "imager-data," limits overall utility. No cloud base height product currently planned for N' era.

[14] In general, other data sources dominate in the production of this EDR. "Red" ratings here due mainly to 5D3/K-N' "era" data processing limitations/plans.

[15] Rated here as "orange", but could also be categorized a "red" relative to IORD threshold. In general, other data sources (such as altimetry and ocean color) are required in the production of this EDR. Multispectral data from POES provides very limited imagery-derived data source only (i.e. no altimetry or ocean color data).

[16] Categorized here a "red" as in "no capability" relative to IORD threshold. In general, other data sources such as ocean color are required to produce a quantitative EDR product. DMSP and POES provide limited qualitative imagery-derived data only.

[17] Fails to address EDR in several respects: HSR, mapping accuracy. Note: No wind direction information provided either, although strictly speaking only a scalar EDR product is required for this parameter as described in IORD-I.

[18] Categorized here a "red" as in "no capability" relative to IORD threshold. In general, other data sources such as ocean color are required to produce a quantitative EDR product. POES provides a somewhat limited qualitative radiometric-derived data product for Chesapeake Bay area only.

[19] Categorized here a "red" as in "no capability" relative to IORD threshold. In general, other data sources such as that obtained from a wind lidar are required to produce a directly sensed quantitative EDR product. DMSP provides a limited sounding-derived data product for the geostrophic wind profile only.

[20] Categorized here a "red" as in "no capability" relative to IORD threshold. In general, very high resolution UV/IR imager is required to produce EDR product. DMSP provides an extremely limited capability with the SSUSI and SSULI sensors.

Table C-3. DMSP Block 6 and NOAA O,P,Q,R Descriptions

DMSP Block 6

A total of six (6) spacecraft (with Delta II launch vehicles) were planned to be acquired under the Block 6 Program. The mission payload for each satellite is identical and includes the following:

Sensor	Sensor Description
Operational Multi-Spectral Imager Suite (OMIS)	7-8 channel imager (.4-.8 km visible/infrared, 3.25 km LL)
Microwave Imager Sensor Suite (MISS)	Conical microwave imager/ sounder
Space Environmental Sensor Suite (SESS)	SSIES, SSULI, SSUSI, SSM, SSJ/5 (plus enhancements)
Surface Data Collection	data collection system

NOAA O,P,Q,R

A total of four (4) spacecraft (with Delta II launch vehicles) were planned to be acquired under the Block 6 Program. The mission payload for each satellite is identical and includes the following:

Sensor	Sensor Description
Visible Infra-Red Scanning Radiometer [1]	7 channel radiometer
Interferometer Thermal Sounder	Cross-track infrared sounder - interferometer
Atmospheric Microwave Sounding Unit -A [1] (upgrade)	Cross-track microwave temperature sounder
Microwave Humidity Sounder [1]	Cross-track microwave humidity sounder
Space Environment Sensors [1]	TED, MEPED, LEFI
ARGOS/Data Collection System [1], [2]	data collection system
Solar Backscatter Ultraviolet Radiometer/2	Ozone profiler - nadir view
Search and Rescue System [1], [2]	Search and rescue

Notes: [1] Will also fly on METOP-1/2 in the 0930 orbit;
[2] Provided by foreign governments to fly on NN'

Table C-4. System Capability Assessment
(DMSP Block 6, NOAA O,P,Q,R plus METOP)
(last revised 9 June 1996)

Assumptions and Caveats: This analysis is a first-order assessment of the overall relative capabilities of the systems listed. System performance relative to each EDR in question was evaluated against the NPOESS IORD-I requirements. Data on individual systems under review was obtained from various sources and therefore is a "mix" of documented performance values (although not always validated), individuals within DoD, DOC, and NASA who provided "expert opinions" on specific performance questions, and extrapolations/projections based on the relative performance of the various sensors under discussion.

CAUTION should used when evaluating the color-code data assessments. Due to the number of factors involved, a large "subjective element" is inherent in any assessment of the systems under discussion. All questions regarding this assessment or issues it may raise should be referred to the NPOESS IPO for detailed discussion/resolution. IPO POC: Mr. Donald Blersch (301) 427-2077 (x 165).

IORD-I (Dec '95)[1]	**DMSP BLOCK 6**	**NOAA O,P,Q,R** (w/METOP)	**BLK6& OPQR** (w/METOP)
Key Parameters (6)			
Vertical Moisture Profile	Yellow[2]	Blue[3]	Blue
Measurement Accuracy	*Yellow[4]*	*Blue*	*Blue*
Vertical Temperature Profile	Yellow[5]	Blue	Blue
Measurement Accuracy	*Yellow[6]*	*Blue*	*Blue*
Imagery	Yellow[7]	Yellow	Yellow
Horizontal Resolution	*Green*	*Orange*	*Green*
Refresh	*Yellow*	*Yellow*	*Green*
Sea Surface Temperature	Yellow	Green	Green
Horizontal Resolution	*Yellow[8]*	*Green*	*Green*
Measurement Accuracy	*Yellow[9]*	*Green*	*Green*
Sea Surface Winds (Sp&Dir)	Yellow[10]	Red	Yellow
Measurement Accuracy (Sp)	*Green*	*Red*	*Green*
Soil Moisture (Surface)	Yellow[11]	Red	Yellow
Sensing Depth	*Green*	*Red*	*Green*

Table C-4. (continued)

IORD-I (Dec '95)[12]	**DMSP BLOCK 6**	**NOAA O,P,Q,R** (w/METOP)	**BLK6& OPQR** (w/METOP)
Atmospheric Parameters (8)			
Aerosol Optical Thickness	Yellow	Green	Green
Aerosol Particle Size	Yellow	Green	Green
Ozone Total Column/Profile	Red	Yellow	Yellow
Precipitable Water	Yellow	Green	Green
Precipitation Type/Rate	Yellow[13]	Green	Green
Pressure (Surface/Profile)	Yellow	Green	Green
Suspended Matter	Yellow	Green	Green
Total Water Content	Yellow	Green	Green
Cloud Parameters (9)			
Cloud Base Height	Orange	Yellow	Yellow
Cloud Cover/Layers	Yellow	Yellow	Yellow
Cloud Effective Particle Size	Orange	Green	Green[14]
Cloud Ice Water Path	Green	Green	Green
Cloud Liquid Water	Green	Green	Green
Cloud Optical Depth/Transmittance	Yellow	Yellow	Yellow
Cloud Top Height	Yellow	Green	Green
Cloud Top Pressure	Yellow	Green	Green
Cloud Top Temperature	Yellow	Green	Green
ERB Parameters (6)			
Albedo (Surface)	Orange	Green	Green
Dwn Longwave Rad (Surf)	Red	Yellow	Yellow
Insolation	Red	Yellow	Yellow
Net Shortwave Rad (TOA)	Red	Yellow	Yellow
Solar Irradiance	Red	Red	Red
Total Longwave Rad (TOA)	Red	Yellow	Yellow
Land Parameters (4)			
Land Surface Temperature	Yellow	Green[15]	Green
Normalized Diff Veg Index	Red	Green	Green
Snow Cover/Depth	Yellow[16]	Yellow	Yellow
Vegetation/Surface Type	Green	Green	Green

Table C-4. (continued)

IORD-I (Dec '95)[17]	**DMSP BLOCK 6**	**NOAA O,P,Q,R** (w/METOP)	**BLK6& OPQR** (w/METOP)
Ocean/Water Parameters (11)			
Currents (Nr Shore & Surface)	Orange	Orange	Orange[18]
Fresh Water Ice Edge Motion	Green[19]	Orange	Green[20]
Ice Surface Temperature	Yellow[21]	Green[22]	Green
Littoral Sediment Transport	Orange[23]	Orange[24]	Orange
Net Heat Flux	Orange	Green	Green
Ocean Color/Chlorophyll	Red	Red	Red
Ocean Wave Characteristics	Red	Red	Red
Sea Ice Age & Edge Motion	Green[25]	Orange	Green
Sea Surface Height/Topography	Red	Red	Red
Surface Wind Stress	Green[26]	Red	Green
Turbidity	Red	Red	Red
SES Parameters (17)			
Auroral Boundary	Yellow	Red	Yellow
Total Auroral Energy Deposit	Green	Red	Green
Auroral Imagery	Yellow	Red	Yellow
Electric Field	Green	Red	Green
Elect Den Profile/Iono Spec	Yellow	Red	Yellow
Geomagnetic Field	Green	Red	Green
In-situ Ion Drift Velocity	Green	Red	Green
In-situ Plasma Density	Green	Orange	Green
In-situ Plasma Fluctuations	Green	Orange	Green
In-situ Plasma Temperature	Green	Orange	Green
Ionospheric Scintillation	Green	Red	Green
Neutral Den Profile/Atmos Spec	Yellow	Red	Yellow
Rad Belt/Low Energy Sol Part	Green	Orange	Green
Solar Gal Cosmic Ray Particles	Green	Orange	Green
Solar EUV Flux	Red	Red	Red
Supra Thermal/Auroral Particle	Green	Red	Green
Upper Atmosphere Airglow	Yellow	Red	Yellow

Table C-4. (continued)

IORD-I (Dec '95)[27]	**DMSP BLOCK 6**	**NOAA O,P,Q,R** (w/METOP)	**BLK6& OPQR** (w/METOP)
P^3I EDRs (9)			
Tropospheric Winds	Red	Red	Red
Ozone Profile - High Resolution	Red	Red	Red
Methane (CH_4) Column	Red	Red	Red
Carbon Monoxide (CO) Column	Red	Red	Red
Carbon Dioxide (CO_2) Column	Red	Red	Red
Optical Backgrounds	Red	Red	Red
Bathymetry (DpOc&NrSh)	Red	Red	Red
Bioluminescence	Red	Red	Red
Salinity	Red	Red	Red
System Parameters (12)			
Data Access (Key)	*Green*	*Orange*	*Yellow*
Data Availability	Green	Green	Green
Autonomous Operations	Green	Yellow	Yellow
Stored High Resolution Data	Green	Yellow	Yellow
Surface Data Collection	Green[28]	Green	Green
Orbital Characteristics	Green	Orange	Yellow
System Survivability	Blue	Red	Yellow
Search and Rescue	Red	Green	Green
Compatibility	Orange	Yellow	Yellow
Space Debris Minimization	Red	Red	Red
Space Environ Constell Char	Yellow	Yellow	Yellow
Geolocation of Data	Green	Yellow	Yellow

KEY: **Red**-No Capability; **Orange**-Sig Below Threshold; **Yellow**-Below Threshold; **Green**-Meets Threshold; **Blue**-Exceeds Threshold.

ENDNOTES:

[1] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[2] Blk6 MISS approaches IORD-I accuracy requirement but 25 km HSR falls short of 15 km HSR requirement.
[3] ITS sounder exceeds IORD-I AVMP requirement.
[4] Blk6 MISS accuracy meets IORD-I threshold over water, 35% accuracy fails over land.
[5] Accuracy (3K -0.5K) and HSR (25 km) fall short of IORD-I thresholds.
[6] VTP accuracy averaged over layers comparable to IORD-I, but falls short of vertical sampling requirement.
[7] Nadir mapping accuracy (4 km) falls short of IORD-I (3 km) requirement.
[8] HSR resolution of 4 km falls short of 3 km global nadir IORD-I Sea Surface Temperature requirement.
[9] Accuracy of 1 K falls short of 0.5 K IORD-I requirement for Sea Surface Temperature.
[10] Blk6 MISS aperture increase over SSM/IS provides enhanced Sea Surface wind speed and horizontal resolution (25 km), but falls short of 20 km HSR and mapping accuracy IORD-I thresholds. Note: No Stokes channels on MISS to provide wind direction.
[11] Enhanced resolution and sensitivity of Blk6 MISS over SSM/IS resulting from increase in aperture, coupled with high resolution multispectral imager.
[12] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[13] Block 6 measurement range (50 mm/hr), mapping accuracy (4 km) fall short of IORD-I thresholds.
[14] ITS assumed to significantly increase performance for these and following parameters for this system
[15] Additional imager thermal channel and ITS assumed to satisfy LST requirement.
[16] Blk6 MISS does not meet cloudy HSR threshold requirement of 12.5 km.
[17] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[18] Rated here as “orange”, but could also be categorized a “red” relative to IORD threshold. In general, other data sources (such as altimetry and ocean color) are required in the production of this EDR.
[19] High resolution imager’s improved multispectral content enhances ice parameter performance.
[20] High resolution imager’s improved multispectral content enhances ice parameter performance.
[21] Increased number of thermal channels on VIS/IR imager potentially improves ice temperature performance; however, lack of absolute calibration results in shortfall relative to IORD-I accuracy threshold.
[22] Additional MWIR/LWIR thermal channel potentially improves EDR accuracy.
[23] Increased multispectral content of image in visible channels at high resolution provides limited increase in performance.
[24] Additional spectral channels potentially provide limited increase in capability. High spatial resolution ocean color bands presumed required for full satisfaction of IORD-I.
[25] Increased number of spectral bands in high resolution imager provides improvements to product.
[26] 50 km Blk6 MISS horizontal resolution satisfies 50 km HSR IORD-I threshold requirement.
[27] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[28] Surface Data Collection system added to DMSP Block 6 satellites.

APPENDIX D

COBRA ALTERNATIVE DESCRIPTIONS

This appendix describes the Cost, Operational Benefit, and Requirements Analysis (COBRA) alternatives, including the spacecraft on which specific notional sensors will fly and a detailed description of the notional sensors used in each alternative. For the National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellites, Tables D-1 through D-4 present COBRA alternative payload by satellite/nodal crossing time. The association of these specific sensors to satisfy NPOESS Environmental Data Records (EDRs) is detailed in Table D-5, along with an assessment of whether the instrument contributes to EDR satisfaction on a primary, secondary, or potential contribution basis. Finally, the system performance of each alternative against the individual Integrated Operational Requirements Document (IORD)-I EDR thresholds is depicted in Table D-6. Performance of current and planned systems (5D3 and K-N' plus METOP, Block 6 and O,P,Q,R) is shown in Appendix C.

This appendix is organized as follows: Alternative 1 is described first, since its instruments, space, C^3 and ground processing segments are the same for all alternatives. Alternative 1 sensor descriptions, therefore, are not repeated for Alternatives 2 through 3B. Similarly, the space, C^3 and ground processing segments are not repeated for Alternatives 2 through 3B. Only additional sensors (i.e., those that are different from Alternative 1) are described for the remaining alternatives.

D.1 ALTERNATIVE 1

The COBRA Alternative 1 sensor configuration is shown in Table D-1 by satellite, followed by a description of each of the instruments, the space, C^3 segment, and the ground processing segments for Alternative 1, which are all common to the other COBRA alternatives. Tables D-2 through D-4 provide similar payload information for the remaining three COBRA alternatives, followed by a description of payloads unique to that alternative.

The performance of the Alternative 1 constellation, and, therefore, of all alternative constellations, satisfies all of the IORD-I system-level requirements[1]. These include the general space, launch, C^3, and ground processing segment requirements in IORD-I Section 1.3; the operational and support concept requirements in IORD-I Section 1.4; and the threat requirements in IORD Section 2. Furthermore, each of the alternatives satisfies the specific "system characteristics" requirements in IORD-I Section 4.1.5, including data availability, autonomous operations, stored high resolution data, surface data collection, orbital characteristics, system survivability[2], search and rescue, compatibility, space debris minimization, data access, geolocation of data, and space environmental constellation characteristics.

Table D-5 depicts specific sensors associated with the satisfaction of specific EDRs, along with an assessment of whether the instrument contributes to EDR satisfaction on a primary, secondary, or potential contribution basis. Table D-5 is instrument specific, vice alternative dependent, so the contribution of the four primary instruments (Imager/Radiometer, Sounder, Temperature Sounder, and Imager/Sounder) applies to all of the alternatives. Similarly, the other (secondary) instruments (Ozone Monitor, Low Light VIS Imager, Data Collection System, Search and Rescue, and Space Environmental Suite instruments apply to all of the alternatives. The remaining instruments listed apply to at least one of the remaining three COBRA alternatives.

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[1]Recall that only Alternative 1 does not meet the non-key DoD "system survivability" requirement (IORD-I, Paragraph 4.1.5.6). Alternatives 2, 3A, and 3B do meet the survivability requirement.
[2] Ibid

The system performance of each alternative against the individual IORD-I EDR thresholds is depicted in Table D-6, Capability Comparison Chart. The ability of this alternative to meet IORD-I thresholds is assessed using a color rating. The performance of the current on-orbit systems (5D3 and NN') is shown, both as separate systems and a combined system, in Appendix C for reference.

Table D-1. COBRA Alternative 1 Notional Payload Configuration

USG Payloads	0530	1330	EUM**
VIS/IR Imager Radiometer	X*	X*	X*
Low Light VIS Imager	X	X	X
Cross-track IR Sounder		X*	
Cross-track MW Temperature Sounder		X*	X*
Conical MW Imager/Sounder	X*	X*	X*
Ozone Monitor		X	
Data Collection System	X	X	X
Search and Rescue	X		X
Space Environmental Suite (SES)	X	X	X
* Assumed Critical Payload			
**Assumes European IR sounder (IASI) included on 0930 EUMETSAT spacecraft			

The following are the descriptions of the specific notional instruments included in Alternative 1:

<u>VIS/IR Imager/Radiometer</u>

Seven Channels

- Approximate band selections: 0.61-0.63; 0.86-0.88; 1.54-1.66; 3.53-3.93; 8.4-8.7; 10.5-11.5; 11.5-12.5 microns

Horizontal Spatial Resolution (HSR)

- Real-time data: 0.4-0.8 km
- Stored data: 0.4-0.8 km for 2/3 of orbit; 2.4 km for 1/3 of orbit (user selectable)

Mass: 149 kg (includes 50% contingency)

On-orbit average power: 194 W (includes 25% contingency)

Real-time data rate: 6.5 Mbps

Imagery and sea surface temperature (SST) refresh requirements drive the need for three instruments per constellation (one per each orbit plane)

- Four (4) hour imagery refresh: 3 instruments with 100% coverage
- Six (6) hour SST refresh and data quality: 3 instruments with < 100% coverage

<u>Low-Light VIS Imager</u>

Single channel broad-band visible (0.4-1.0 microns)

Multiple telescope pushbroom instrument

2.6 km HSR

Mass: 8kg (includes 30% contingency)

Power: 44W (includes 20% contingency)

Minimization of sun-shade leads to separate instrument solution

- Potential for greatly improved sensitivity for relatively small sensor

Imagery and SST refresh requirements drive the need for three instruments per constellation (one per each orbit plane)

- Four (4) hour imagery refresh: 3 instruments with 100% coverage
- Six (6) hour SST refresh and data quality: 3 instruments with < 100% coverage

Cross-track IR Sounder

Cross-track scanning interferometer sounder

- Based on MIT Lincoln Labs Interferometer Thermal Sounder (ITS) concept

Approximately 1400 channels

- Three spectral bands

1.2 Mbps data rate

Mass: 81kg (includes 50% contingency)

On-orbit average power: 91W (includes 25% contingency)

Atmospheric temperature and moisture profiles refresh and accuracy requirements drive the need for two instruments per constellation; operational requirements of forecasting models drives the need for the U. S. instrument on the 1330 orbit and data from the 0930 orbit*

* Assume an IR sounder is provided on the 0930 orbit by EUMETSAT

Cross-track MW Temperature Sounder

Modeled after "Advanced Microwave Sounding Unit (AMSU)-A1 like" instrument

12 channels ~50 Ghz for lower air soundings

Mass: 67kg (includes 25% contingency)

On-orbit average power: 77W (includes 10% contingency)

Atmospheric temperature profile refresh and accuracy requirements drive two instruments per constellation

Conical Microwave Imager/Sounder

48 channels

- Lower air sounding: 9 channel ~50 Ghz
- Moisture sounding: 2 chs ~150 Ghz; 6 chs ~ 183 Ghz
- Imaging: 4 chs ~6 Ghz; 4 chs ~10 Ghz; 4 chs ~19 Ghz; 4 chs ~37 Ghz: 1 ch ~22 Ghz; 2 chs ~90 Ghz
- Upper air sounding: 12 chs ~60 Ghz

Mass: 201 kg (includes 30% contingency)

On-orbit average power: 227 W (includes 20% contingency)

Atmospheric temperature profile refresh requirement of six (6) hours drives lower air sounding channels

Sea surface wind speed HSR and refresh drive sensor size and the need for three instruments per constellation (one per each orbit plane)

- 20 km HSR (19 Ghz channels) and six (6) hour refresh
- 2.2 m antenna with 53 degree earth incidence angle (EIA)

Ozone Monitor

Solid state column/profile instrument

Mass: 45 kg (includes 50% contingency)

On-orbit average power: 38 W (includes 25% contingency)

Requires ozone total column/profile

Refresh requirements drive need for one instrument per constellation; science drives position on 1330 satellite

Data Collection System

Modeled after “ARGOS”

Provided “free” to U.S. from France

Mass: 68 kg (includes 3% contingency)

On-orbit average power: 70W (includes 3% contingency)

Operational requirements drive the need for three instruments per constellation (one per each orbit plane)

Search and Rescue

Modeled after “SARSAT”

Provided “free” to U.S. from Canada/France

Mass: 46 kg (includes 3% contingency)

On-orbit average power: 67W (includes 3% contingency)

Mass and power estimates are probably conservative

- Canadian Ministry of Defense planning to redesign instrument
- Updated technology will likely drive size down

Flown on one U. S. satellite (on the 0530 orbit, it is impacted less by instrument size)

- Consistent with pre-convergence plan of 1 US satellite (POES O series)
- Expect EUMETSAT to fly other package

Space Environmental Suite (EUV/FUV Nadir Imager)

Heritage: SSUSI, HILAT, Polar Bear

Mass: 19 kg (includes 25% contingency)

On-orbit average power: 7 W (includes 10% contingency)

EDRs required: Auroral boundary, auroral imagery, upper atmospheric airglow, electron density profiles, neutral density profiles, solar EUV flux

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (Boom Mounted Vector Magnetometer)

Heritage: SSM, MAGSAT, Dynamics Explorer

Mass: 13 kg (includes 30% contingency)

On-orbit average power: 3W (includes 10% contingency)

EDRs Required: auroral boundary, geomagnetic field

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (High Energy Particle Spectrometer)

Heritage: UARS/PEM/NASA

Mass: 8kg (includes 30% contingency)

On-orbit average power: 7 W (includes 10% contingency)

EDRs required: radiation belt/low energy, solar and galactic cosmic ray particles

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (Global Positioning System (GPS) Receiver)

Multiple GPS receivers for occultation measurements

Heritage: GPS receiver and antenna/Topography Experiment for Ocean Circulation (TOPEX),

GPS/MET

Mass: 9kg (includes 30% contingency)

On-orbit average power: 14W (includes 10% contingency)

EDRs required: auroral boundary, electron density profiles, in-situ plasma density, ionospheric scintillation

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (Retarding Potential Analyzer and Drift Meter)

Heritage: SSIES, Dynamics Explorer

Mass: 14 kg (includes 25% contingency)

On-orbit average power: 12 W (includes 10% contingency)

EDRs required: electric field, electron density profiles, in-situ plasma density, in-situ plasma temperature, in-situ ion drift velocity, ionospheric scintillation, in-situ plasma fluctuations

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (Medium Energy Particle Spectrometer)

Heritage: SSJ5, CERES

Mass: 10 kg (includes 25% contingency)

On-orbit average power: 7 W (includes 10% contingency)

EDRs required: auroral boundary, total auroral energy, supra-thermal auroral particles, radiation belt/low energy

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (Ionospheric Scintillation: Bi-Static Radio Instrument)

Heritage: Wide-band/DNA, HILAT

Mass: 17 kg (includes 30% contingency)

On-orbit average power: 17 W (includes 10% contingency)

EDRs required: electron density profiles, ionospheric scintillation

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

Space Environmental Suite (EUV/FUV Limb Imager)

Heritage: SSULI, ABIS

Mass: 20 kg (includes 30% contingency)

On-orbit average power: 7 W (includes 10% contingency)

EDRs required: optical backgrounds, auroral imagery, upper atmospheric airglow, electron density profiles, neutral density profiles

Initial science requirements assessment drives the need for three instruments (one per each orbit plane); may revise based on additional Phase I analysis

The following are the descriptions of the notional space, C^3, and ground processing segments for Alternative 1, which are common to COBRA Alternatives 2 through 3B.

Space Segment

3 satellite constellation

- U.S.: 0530 Ascending (A), 1330 A
- EUMETSAT: 0930 Descending (D)
- Recognize requirement for any nodal crossing time; satellite sized for "worst case" orbit of 1200A

833 km, sun-synchronous

Assume Delta II-7920 as medium launch vehicle (MLV)

- Performance to notional orbit: approximately 3200 kg

Assume common spacecraft for all satellite configurations

Growth margin reserved for Tracking Data Relay Satellite System (TDRSS) crosslink

C^3 Segment

Command and Control (C^2)

- Primary Satellite Operations Center (SOC) at Suitland
- Backup at Falcon AFB
- Fairbanks, Wallops, and AFSCN available for C^2

5 CDA/RTS sites for stored mission data retrieval

- Downlink data rate > 60 Mbps
- Fairbanks, Wallops, Thule, Oakhanger
- 1 EUMETSAT site

Stored mission data routing

- DOMSAT links: Single - 2; Dual - 1
- Fiber Optic links: T-1 - 39; T-3 - 6

Time bandwidth exchange of 1:1.5

- Reduce data routing data rate to <45 Mbps to keep DRR costs down
- Estimate still able to meet 30 minute timeliness, although will discuss relief of requirement to 35 minute with Joint Agency Requirements Group (JARG)

IDP Segment - Centrals

Four Centrals

- NESDIS: Raw Data Record (RDR) receipt only
- AFGWC: RDR receipt and Environmental Data Record (EDR) processing
- FNMOC: RDR receipt and EDR processing
- 50th SW: RDR receipt and EDR processing of Space Environmental parameters only

Issues

- Location of “wall” between user sites and Interface Data Processing Segment (IDPS) - significantly impacts software estimates
- Type of data to each IDPS Central

IDP Segment - Regionals

Required to mod DoD terminals in place at time of IOC

- Assumed existing terminals for initial cost estimates
- SST Basic, STT Enhanced, STT JT-FST, MK-IVB, AN/SMQ-11 & TESS 3, Marine MK-IV

HRPT data rate - 4.7 Mbps

- Revised Imagery requirement drove data rate above initial 3.5 Mbps baseline
- Trade of data rate versus compression of EO data required

LRPT data rate - 161 kbps

- Revised Imagery requirement drove data rate above initial 75 kbps baseline
- Trade of data rate versus compression of EO data versus smoothing of data required

Issues

- Location of “wall” between user sites and IDPS - seriously impacts software estimates
- Type of data to each IDPS Regional

D.2 ALTERNATIVE 2

The COBRA Alternative 2 sensor configuration is shown in Table D-2 by satellite, followed by a description of each of the new instruments. The instruments described for Alternative 2 (Imager/Radiometer with ocean color channels, Earth Radiation Budget Sensor, Solar Irradiance Sensor, and Radar Altimeter) are the only unique instruments in this alternative, all other instruments and space, C^3 and ground processing segments have been previously described in section D.1 (Alternative 1).

Table D-5 depicts specific sensors associated with the satisfaction of specific EDRs, along with an assessment of whether the instrument contributes to EDR satisfaction on a primary, secondary, or potential contribution basis. EDRs satisfied by Alternative 2 are associated with the above instruments as well as those discussed under section D.1 (Alternative 1). The performance of the Alternative 2 constellation satisfies all of the IORD-I system-level requirements at threshold levels. In addition to providing Alternative 1 EDRs, Alternative 2 satisfies the remaining five Earth Radiation Budget parameters and the remaining six Ocean/Water parameters.

The system performance of Alternative 2 against the individual IORD-I EDR thresholds is depicted in Table D-6, Capability Comparison Chart. The ability of this alternative to meet IORD-I thresholds is assessed using a color rating. Again, the performance of the current on-orbit systems (5D3 and NN’) is shown in Appendix C for reference.

Table D-2. COBRA Alternative 2 Notional Payload Configuration

USG Payloads	**0530**	**1330**	**EUM****
VIS/IR Imager Radiometer **w/Ocean Color**	**X***	**X***	**X***
Low Light VIS Imager	X	X	X
Cross-track IR Sounder		X*	
Cross-track MW Temperature Sounder		X*	X*
Conical MW Imager/Sounder	X*	X*	X*
Ozone Monitor		X	
Data Collection System	X	X	X
Search and Rescue	X		X
Space Environmental Suite (SES)	X	X	X
Earth Radiation Budget		**X**	
Solar Irradiance Sensor	**X**		
Radar Altimeter	**X**		
* Assumed Critical Payload			
**Assumes European IR-sounder (IASI) included on 0930 EUMETSAT spacecraft			
Bold indicates changes to Alternative 1 configuration			

The following are the descriptions of the new instruments included in Alternative 2:

VIS/IR Imager/Radiometer with Ocean Color Channels

13 Channels

- Approximate band selections: 0.61-0.63; 0.86-0.88; 1.54-1.66; 3.53-3.93; 8.4-8.7; 10.5-11.5; 11.5-12.5 microns; 6 vis ocean color bands

HSR

- Real-time data: 0.4-0.8 km: ocean color at 1.3 km
- Stored data: 0.4-0.8 km for 2/3 orbit; 2.4 for 1/3 of orbit (user selectable); ocean color at 1.3 km

Mass: 149 kg (includes 50% contingency)

On-orbit average power: 202 W (includes 30% contingency)

Real-time data rate: 6.920 Mbps

Imagery and sea surface temperature (SST) refresh requirements drive the need for three instruments per constellation

- Four (4) hour imagery refresh: 3 instruments with 100% coverage
- Six (6) hour SST refresh and data quality: 3 instruments with < 100% coverage

Earth Radiation Budget Sensor

Modeled after “CERES” instrument

Mass: 48 kg (includes 5% contingency)

On-orbit average power: 50W (includes 5% contingency)

EDRs required: Long wave radiation, net radiation, net surface shortwave radiation, total longwave radiation, total shortwave radiation

Refresh requirements drive need for one per constellation; science drives position on 1330 satellite

Total Solar Irradiance Sensor

Modeled after “ACRIM-like” instrument

Mass: 49 kg (includes 25% contingency)

On-orbit average power: 39 W (includes 10% contingency)

EDRs required: net shortwave radiation, total shortwave radiation, total solar irradiance

Refresh requirements drive need for one instrument per constellation; science drives position on 0530 satellite

Radar Altimeter

Dual-frequency (C & Ku band)

Heritage: TOPEX/POSEIDON; GFO (Geosat Follow-on)

Mass: 93 kg (includes 50% contingency)

On-orbit average power: 88 W (includes 25% contingency)

1.14 m reflector antenna

EDRs/measurements required: ocean currents, ocean wave characteristics, sea surface height/topography, wave spectral energy

Refresh requirements drive the need for one instrument per constellation; 0530 satellite chosen to minimize spacecraft impacts (it has considerable payload growth potential)

Repeat orbit requirements have possible impact on spacecraft

D.3 ALTERNATIVE 3A

The COBRA Alternative 3A sensor configuration is shown in Table D-3 by satellite, followed by a description of the Wind Lidar, which is the only addition to Alternative 2. The Wind Lidar is flown on a smallsat (free-flier).

Table D-5 depicts the specific sensors associated with the satisfaction of specific EDRs, along with an assessment of whether the instrument contributes to EDR satisfaction on a primary, secondary, or potential contribution basis. In addition to providing Alternative 1 and Alternative 2 EDRs, Alternative 3A satisfies one P^3I EDR, direct measurement of tropospheric winds. The performance of the Alternative 3A constellation satisfies all of the IORD-I system level requirements at threshold levels.

The system performance of Alternative 3A against the individual IORD-I EDR thresholds is depicted in Table D-6, Capability Comparison Chart. The ability of this alternative to meet IORD-I thresholds is assessed using a color rating. Again, the performance of the current on-orbit systems (5D3 and NN’) is shown in Appendix C for reference.

Table D-3. COBRA Alternative 3A Notional Payload Configuration

USG Payloads	0530	1330	EUM**	Free-Flier
VIS/IR Imager Radiometer w/Ocean Color	X*	X*	X*	
Low Light VIS Imager	X	X	X	
Cross-track IR Sounder		X*		
Cross-track MW Temperature Sounder		X*	X*	
Conical MW Imager/Sounder	X*	X*	X*	
Ozone Monitor		X		
Data Collection System	X	X	X	
Search and Rescue	X		X	
Space Environmental Suite (SES)	X	X	X	
Earth Radiation Budget		X		
Solar Irradiance Sensor	X			
Radar Altimeter	X			
Wind Lidar				**X**
* Assumed Critical Payload				
**Assumes European IR-sounder (IASI) included on 0930 EUMETSAT spacecraft				
Bold indicates changes to Alternative 2 configuration				

The following is the description of the new instrument included in Alternative 3A:

Wind Lidar

Modeled after scaled-down Doppler wind lidar "concept" proposed in FY95 internal government study effort (see active sensor study/P^{3}I white paper[3])

Heritage: Laser Atmospheric Wind Sounder (LAWS)

Mass: 425 kg

On-orbit average power: 520 W

Data rate: 1.75 Mbps

EDRs required: tropospheric winds

Refresh requirements drive need for one per constellation; accommodation drives free-flyer approach

[3] White Paper on "Issues related to NPOESS IORD-I Potential Pre-planned Product/Process Improvements, D. Blersch, NPOESS IPO, May 9, 1996

D.4 ALTERNATIVE 3B

The COBRA Alternative 3B sensor configuration is shown in Table D-4 by satellite, followed by a description of the instruments (Enhanced Ozone Profiler, CH_4/CO Monitor, and CO_2 Monitor) added to Alternative 2. Note that the Wind Lidar is not included in this alternative as it was in Alternative 3A.

Table D-5 depicts the specific sensors associated with the satisfaction of specific EDRs, along with an assessment of whether the instrument contributes to EDR satisfaction on a primary, secondary, or potential contribution basis. In addition to providing Alternative 1 and 2 EDRs, Alternative 3B provides for satisfaction of four P^3I EDRs: enhanced ozone (high resolution), methane column, carbon monoxide column, and carbon dioxide column. However, the tropospheric wind EDR is not satisfied in this alternative, since the Wind Lidar is not included in the Alternative 3B configuration. The performance of the Alternative 3B constellation satisfies all of the IORD-I system level requirements at threshold levels.

The system performance of Alternative 3B against the individual IORD-I EDR thresholds is depicted in Table D-6, Capability Comparison Chart. The ability of this alternative to meet IORD-I thresholds is assessed using a color rating. Again, the performance of the current on-orbit systems (5D3 and NN') is shown in Appendix C for reference.

Table D-4. COBRA Alternative 3B Notional Payload Configuration

USG Payloads	0530	1330	EUM**	Free-Flier
VIS/IR Imager Radiometer w/Ocean Color	X*	X*	X*	
Low Light VIS Imager	X	X	X	
Cross-track IR Sounder		X*		
Cross-track MW Temperature Sounder		X*	X*	
Conical MW Imager/Sounder	X*	X*	X*	
Ozone Monitor				**X**
Data Collection System	X	X	X	
Search and Rescue	X		X	
Space Environmental Suite (SES)	X	X	X	
Earth Radiation Budget		X		
Solar Irradiance Sensor	X			
Radar Altimeter	X			
Ozone Profiler - High Resolution				**X**
CH_4/CO Monitor				**X**
CO_2 Monitor				**X**
* Assumed Critical Payload				
**Assumes European IR-sounder (IASI) included on 0930 EUMETSAT spacecraft				
Bold indicates changes to Alternative 2 configuration				

The following are the descriptions of the new instruments included in Alternative 3B:

Ozone Profiler - High Resolution

Modeled after “MAS/MLS-like” microwave limb-scanner spectrometer

Heritage: MAS/MLS (microwave limb-scanner spectrometer); HIRDLS (IR limb-scanner)

Features: Profile measurements, 3 km vertical resolution, no aerosol problem

Mass: 120 kg

Power: 140 W

EDRs/measurements required: High-resolution ozone (3 km vs. 5 km) to be used in conjunction with nadir scanning total column/profile ozone monitor (see Alternative1)

Refresh requirements drive need for one instrument per constellation; accommodation drives free-flier

CH_4/CO Monitor

Modeled after “MOPITT-like” instrument

Mass: 108.75 kg (includes 25% contingency)

On-orbit average power: 220 W (includes 10% contingency)

EDRs required: Methane (CH_4) column, carbon monoxide (CO) column

Refresh requirements drive need for one instrument per constellation; accommodation drives free-flier

CO_2 Monitor

Notional sensor, no heritage

Used sensor construct similar to MOPITT for accommodation/costing purposes

Mass: 108.75 kg (includes 25% contingency)

On-orbit average power: 220 W (includes 10% contingency)

EDRs required: Carbon Dioxide (CO_2) column

Refresh requirements drive need for one instrument per constellation; accommodation drives free-flier

Table D-5. Sensor Satisfaction of EDRs

This table maps the notional sensors to the EDRs to which they contribute. Many of the sensors in question provide a mix of data that must be used in concert to produce a specific EDR product. In the matrix, "P" indicates a primary data product source, while an "S" indicates a secondary (and/or ancillary) data product source. These ratings are used to describe, for the EDRs/sensors in question, HOW the data from each sensor "plays together" to support the production of the EDR in question. The ratings should not be seen as an indication that a particular sensor is in any way unimportant or of only negligible added benefit (i.e., could be dropped) due to the fact that its data is not the primary data source. The data from all the relevant sensors are tied together to produce an EDR and therefore important to the EDR's production.

EDRs	Imager/ Radio meter (VIS/IR/ LL)	Sounder (IR X-track)	Temp Sounder (MW X-track)	Imager/ Sounder (MW Conical)	Ozone Monitor
Key EDRs (6):					
Vertical Moisture Profile	S	P	P	P	
Vertical Temp Profile	S	P	P	P	
Imagery	P			P	
Sea Surface Temperature	P	S		S (all WX)	
Sea Surface Winds				P	
Soil Moisture (Surface)	P - (clear)			P (cloudy)	
Atmosphere EDRs (8):					
Aerosol Opt. Thickness	P				
Aerosol Particle Size	P				
Ozone Column/Profile					P
Precipitable Water		P	P	P	
Precipitation (Type/Rate)	S	S		P	
Pressure (surf/prof)		P	P	P	
Suspended Matter	P				
Total Water Content	S			P	
Cloud EDRs (9):					
Cloud Base Height	P-derived				
Cloud Cover/Layers	P	S	S	S	
Cloud Effective Part Sz	P	S			
Cloud Ice Water Path			P	P	
Cloud Liquid Water			P	P	
Cloud Opt. Depth/Trans	P	S			
Cloud Top Height	P-derived	S-derived	S-derived	S-derived	
Cloud Top Pressure	P-derived	S-derived	S-derived	S-derived	
Cloud Top Temperature	P	S	S	S	

Table D-5. (continued)

EDRs	Imager/ Radio meter (VIS/IR/ LL)	Sounder (IR X-track)	Temp Sounder (MW X-track)	Imager/ Sounder (MW Conical)	CERES (Radio meter)	ACRIM (Spectro meter)	Radar Altimeter (C & Ku band)
ERB Parameters (6):							
Albedo (surface)	P						
Dwn Longwave Rad (surf)					P		
Insolation					P		
Net Shortwave Rad (TOA)					P	S	
Solar Irradiance						P	
Total Longwave Rad (TOA)					P	S	
Land EDRs (4):							
Land Surface Temp	P			S			
Norm Diff Veg Index	P						
Snow Cover/Depth	P (clear)			P (cloudy)			
Veg/Surf Type	P			S			
Ocean/Water EDRs:							
Currents (Near Shore/Surf)	P						P
Freshwater Ice Edge/Motion	P (clear)			P (cloudy)			
Ice Surface Temperature	P (clear)			P (cloudy)			
Littoral Sediment Transport	P						
Net Heat Flux	P	S	S	S			
Ocean Color/Chlorophyll	P						
Ocean Wave Characteristics							P
Sea Ice Age/Edge Motion	P (clear)			P (cloudy)			
Sea Surface Height/Topo							P
Surface Wind Stress				P			
Turbidity	P						

Table D-5. (continued)

EDRs	Imager/ Radiometer (VIS/IR /LL)	ABIS (Limb FUV/ EUV)	AVM (Vector Mag)	HEPS (Part Spect)	GPSR (GPS Rec)	RPA-D (Drift Meter)	MEPS (Spec)	BEACON (Ion Mtr)	NADIS (FUV/ EUV)
SES Parameters (17):									
Auroral Boundary	S	P	S		P		S		
Tot Auroral Energy Dep							P		
Auroral Imagery	S	P							S
Electric Field						P			
Elect Den Prof/Ion Spec		S			P	S		S	S
Geomagnetic Field			P						
Ion Drift Velocity						P			
Plasma Density					P	P			
Plasma Fluctuations						P			
Plasma Temperature						P			
Iono Scintillation					P	S		P	
Neutral Density Profile		S							P
Rad Belt/En Sol Par				P			S		
Sol/Gal CR Particles				P					
Solar EUV Flux		S							P
Supra Ther Auroral Par							P		
Upper Atm Airglow		S							P

Table D-5. (concluded)

EDRs	Wind Lidar	Ozone Profiler (Limb Scanner)	MOPITT (Spectro meter)	TBD (Spectro meter)
Unaccommodated (9)				
Tropospheric Winds	P			
Ozone Profile - Hi Res		P		
CH_4 Column			P	
CO Column			P	
CO_2 Column				P
Optical Backgrounds				
Bathymetry				
Bioluminescence				
Salinity				

Table D-6. System Capability Assessment
(COBRA Alternatives 1, 2, 3A, and 3B)
(Last revised 9 June 1996)

Assumptions and Caveats: This table presents an analysis that is a first-order assessment of the overall relative capabilities of the COBRA Alternatives. System performance relative to each EDR in question was evaluated against the NPOESS IORD-I requirements. Data on individual systems under review was obtained from various sources and therefore is a "mix" of documented performance values (although not always validated), individuals within DOD, DOC, and NASA who provided "expert opinions" on specific performance questions, and extrapolations/projections based on the relative performance of the various sensors under discussion.

CAUTION should be used when evaluating the color-code data assessments. Due to the number of factors involved, a large "subjective element" is inherent in any assessment of the systems under discussion. All questions regarding this assessment or issues it may raise should be referred to the NPOESS IPO for detailed discussion/resolution. IPO POC: Mr. Donald Blersch (301) 427-2077 (x 165).

IORD-I (Dec '95)[1]	**ALT 1**	**ALT 2**	**ALT 3A**	**ALT 3B**
Key Parameters (6)				
Vertical Moisture Profile	Blue[2]	Blue	Blue	Blue
Measurement Accuracy	*Blue*	*Blue*	*Blue*	*Blue*
Vertical Temperature Profile	Blue	Blue	Blue	Blue
Measurement Accuracy	*Blue*	*Blue*	*Blue*	*Blue*
Imagery	Green	Green	Green	Green
Horizontal Resolution	*Green*	*Green*	*Green*	*Green*
Refresh	*Green*	*Green*	*Green*	*Green*
Sea Surface Temperature	Green	Green	Green	Green
Horizontal Resolution	*Green*	*Green*	*Green*	*Green*
Measurement Accuracy	*Green*	*Green*	*Green*	*Green*
Sea Surface Winds (Sp&Dir)	Green[3]	Green	Green	Green
Measurement Accuracy (Sp)	*Green*	*Green*	*Green*	*Green*
Soil Moisture (Surface)	Green[4]	Green	Green	Green
Sensing Depth	*Green*	*Green*	*Green*	*Green*
Atmospheric Parameters (8)				
Aerosol Optical Thickness	Green	Green	Green	Green
Aerosol Particle Size	Green	Green	Green	Green
Ozone Total Column/Profile	Green[5]	Green	Green	Blue[6]
Precipitable Water	Green	Green	Green	Green
Precipitation Type/Rate	Green	Green	Green	Green
Pressure (Surface/Profile)	Green	Green	Green	Green
Suspended Matter	Green	Green	Green	Green
Total Water Content	Green	Green	Green	Green

Table D-6. (continued)

IORD-I (Dec '95)[7]	**ALT 1**	**ALT 2**	**ALT 3A**	**ALT 3B**
Cloud Parameters (9)				
Cloud Base Height	Green	Green	Green	Green
Cloud Cover/Layers	Green	Green	Green	Green
Cloud Effective Particle Size	Green	Green	Green	Green
Cloud Ice Water Path	Green	Green	Green	Green
Cloud Liquid Water	Green	Green	Green	Green
Cloud Optical Depth/Trans	Green	Green	Green	Green
Cloud Top Height	Green	Green	Green	Green
Cloud Top Pressure	Green	Green	Green	Green
Cloud Top Temperature	Green	Green	Green	Green
ERB Parameters (6)				
Albedo (Surface)	Green	Green	Green	Green
Dwn Longwave Rad (Surf)	Yellow	Green[8]	Green	Green
Insolation	Yellow	Green[9]	Green	Green
Net Shortwave Rad (TOA)	Yellow	Green[10]	Green	Green
Solar Irradiance	Red	Green[11]	Green	Green
Total Longwave Rad (TOA)	Yellow	Green[12]	Green	Green
Land Parameters (4)				
Land Surface Temperature	Green	Green	Green	Green
Normalized Diff Veg Index	Green	Green	Green	Green
Snow Cover/Depth	Green	Green	Green	Green
Vegetation/Surface Type	Green	Green	Green	Green
Ocean/Water Parameters (11)				
Currents (Nr Shore & Surface)	Orange[13]	Green[14]	Green	Green
Fresh Water Ice Edge Motion	Green	Green	Green	Green
Ice Surface Temperature	Green	Green	Green	Green
Littoral Sediment Transport	Orange[15]	Green[16]	Green	Green
Net Heat Flux	Green	Green	Green	Green
Ocean Color/Chlorophyll	Red	Green[17]	Green	Green
Ocean Wave Characteristics	Red	Green[18]	Green	Green
Sea Ice Age & Edge Motion	Green	Green	Green	Green
Sea Surface Height/Topography	Red	Green[19]	Green	Green
Surface Wind Stress	Green[20]	Green	Green	Green
Turbidity	Red	Green[21]	Green	Green

Table D-6. (continued)

IORD-I (Dec '95)[22]	ALT 1	ALT 2	ALT 3A	ALT 3B
SES Parameters (17)				
Auroral Boundary	Green	Green	Green	Green
Total Auroral Energy Deposit	Green	Green	Green	Green
Auroral Imagery	Green	Green	Green	Green
Electric Field	Green	Green	Green	Green
Elect Den Profile/Iono Spec	Green	Green	Green	Green
Geomagnetic Field	Green	Green	Green	Green
In-situ Ion Drift Velocity	Green	Green	Green	Green
In-situ Plasma Density	Green	Green	Green	Green
In-situ Plasma Fluctuations	Green	Green	Green	Green
In-situ Plasma Temperature	Green	Green	Green	Green
Ionospheric Scintillation	Green	Green	Green	Green
Neutral Den Profile/Atmos Spec	Green	Green	Green	Green
Rad Belt/Low Energy Sol Part	Green	Green	Green	Green
Solar Gal Cosmic Ray Particles	Green	Green	Green	Green
Solar EUV Flux	Green	Green	Green	Green
Supra Thermal/Auroral Particle	Green	Green	Green	Green
Upper Atmosphere Airglow	Green	Green	Green	Green
P^3I EDRs (9)				
Tropospheric Winds	Red	Red	Green[23]	Red
Ozone Profile - High Res	Red	Red	Red	Green[24]
Methane (CH_4) Column	Red	Red	Red	Green[25]
Carbon Monoxide (CO) Column	Red	Red	Red	Green[26]
Carbon Dioxide (CO_2) Column	Red	Red	Red	Green[27]
Optical Backgrounds	Red	Red	Red	Red
Bathymetry (DpOc&NrSh)	Red	Red	Red	Red
Bioluminescence	Red	Red	Red	Red
Salinity	Red	Red	Red	Red
System Parameters (12)				
Data Access (Key)	*Green*	*Green*	*Green*	*Green*
Data Availability	Green	Green	Green	Green
Autonomous Operations	Green	Green	Green	Green
Stored High Res Data	Green	Green	Green	Green
Surface Data Collection	Green	Green	Green	Green
Orbital Characteristics	Green	Green	Green	Green
System Survivability	Red	Green	Green	Green
Search and Rescue	Green	Green	Green	Green
Compatibility	Green	Green	Green	Green
Space Debris Minimization	Green	Green	Green	Green
Space Environ Constell Char	Green	Green	Green	Green
Geolocation of Data	Green	Green	Green	Green

KEY: **Red-**No Capability; **Orange-**Sig Below Threshold; **Yellow-**Below Threshold; **Green-**Meets Threshold; **Blue-**Exceeds Threshold.

ENDNOTES:

[1] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[2] ITS sounder exceeds IORD-I threshold for AVMP.
[3] Stokes parameters on 2-m aperture CMISS provide speed and direction which meet IORD-I thresholds.
[4] Enhanced resolution and sensitivity of CMISS, coupled with high resolution multispectral imager.
[5] Ozone Profiler provides enhanced performance meeting IORD-I threshold for column/profile EDR.
[6] High Resolution Ozone limb profiler performance exceeds minimal IORD-I Section 4 EDR threshold. Option designed to meet High-resolution Ozone Profile P^3I EDR value in IORD-I.
[7] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[8] CERES satisfies IORD-I Earth Radiation Budget thresholds.
[9] CERES satisfies IORD-I Earth Radiation Budget thresholds.
[10] CERES satisfies IORD-I Earth Radiation Budget thresholds.
[11] ACRIM Solar Irradiance sensor satisfies IORD-I threshold requirement.
[12] CERES satisfies IORD-I Earth Radiation Budget thresholds.
[13] Rated here as “orange”, but could also be categorized a “red” relative to IORD threshold. In general, other data sources (such as altimetry and ocean color) are required in the production of this EDR.
[14] Ocean color channels and altimeter together satisfy thresholds for current product in this and subsequent COBRA alternatives.
[15] Increased multispectral content of image in visible channels at high resolution provides limited increase in performance.
Additional spectral channels potentially provide limited increase in capability. High spatial resolution ocean color bands presumed required for full satisfaction of IORD-I.
[16] Improved performance may result from ocean colors on VIS/IR/LL imager in this an subsequent COBRA alternatives.
[17] Ocean color channels directly address IORD-I thresholds in this and subsequent COBRA alternatives.
[18] Altimeter addressed IORD-I thresholds for ocean wave characteristics in this and subsequent COBRA alternatives.
[19] Altimeter addressed IORD-I thresholds for this sea surface height product in this and subsequent COBRA alternatives.
[20] Note: Wind direction information provides vector EDR quantity, although strictly speaking only a scalar EDR product is required for this parameter as described in IORD-I.
[21] Ocean color channels on VIS/IR/LL imager suite provides enhanced performance for turbidity products in this and subsequent COBRA alternatives.
[22] Dec 95 IORD-I used as relative capability performance reference. Note: AVMP and AVTP values listed in Dec 95 draft were updated in the March 96 draft IORD as a correction only (updated values used here).
[23] Wind lidar satisfies tropospheric wind requirement for this COBRA alternative only.
[24] High Resolution ozone profiler addresses P^3I performance for this COBRA alternative.
[25] MOPPITT sensor satisfies CH_4 column requirement for this COBRA alternative only.
[26] MOPPITT sensor satisfies CO column requirement for this COBRA alternative only.
[27] MOPPITT-like sensor satisfies CO_2 column requirement for this COBRA alternative only.

APPENDIX E

EDR DEFINITION, USE, AND INSTRUMENTATION

The ability to receive specific environmental data is important to both DoD and DOC. Common need for these parameters with specific attribute levels from a polar-orbiter is effected by the known and/or projected improvement of weather prediction models that use environmental data records (EDRs) as input. An EDR is a data record produced when an algorithm is used to convert raw data records (RDRs) to geophysical parameters. Since DOD must have the ability to conduct operations world-wide, DOD must have access to weather data in data-sparse and data-denied areas in order to support all aspects of mission planning. For NOAA, continuous, global measurement of various atmospheric parameters is required to effectively understand trends (and differentiation between human-induced and natural trends) and, therefore, to effectively prescribe environmental policies.

This appendix defines each EDR based on IORD information and discusses the many uses of the information based on database information supplemented with Requirements Correlation Matrix (RCM) II information. The detailed information that was used to develop Appendix E is presented in the COBRA data base[1]. In addition, this appendix delineates the NPOESS sensors that are required to provide each EDR and discusses measurement time as appropriate. Review of data from the COBRA database suggests nine main areas of EDR use. Where there is overlap, only one category may be addressed at the discretion of the Integrated Product Team (IPT). The areas are as follows:

1) General Forecasting - this category encompasses use of an EDR as input into various prediction models and generation of forecasts, to analyze specific phenomena, and to characterize a specific area of interest.

2) C^4I Systems Support - this category encompasses use of an EDR to understand the impact of various weather phenomena on C^4I systems/systems use (applies to systems of both friendly and hostile forces).

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[1] Maintained at the IPO Library

3) Weapon Systems Support - this category encompasses use of an EDR to understand the impact of various weather phenomena on weapon systems and their employment and tactical decision aids (TDAs) and their use (applies to systems of both friendly and hostile forces).

4) Safety of Operations - this category encompasses use of an EDR to understand the impact of the existence of various weather phenomena on the ability to effectively and safely carry out specific missions or mission segments.

5) Navigation/Trafficability - this category encompasses use of an EDR to understand the impact to the mobility of troops and assets.

6) Crew and Site Preparation/Protection - this category encompasses use of an EDR to understand and prepare for the potential negative impacts to personnel, equipment and site construction due to existence of specific weather phenomena.

7) Hazard Identification/Warnings - this category encompasses use of an EDR to determine the impact of weather phenomena in creating or exacerbating a hazard, in monitoring a hazard or in controlling a hazard. This information helps understand specific course of action which must be taken to counter hazards as well.

8) Climate/Atmospheric Monitoring - this category encompasses use of an EDR to understand and characterize both short-term and long-term climate/atmospheric changes on both a local, regional and global scale.

9) Ice/Ocean Analysis - this category encompasses use of an EDR to support ice and ocean analyses.

Key Parameters

EDR: Atmospheric Vertical Moisture Profile (AVMP)

Definition: Relative, specific, and absolute humidity moisture profiles measured as the mass of water vapor per unit volume of air

Uses:

Weapon Systems Support

- AVMP supports understanding and prediction of radar effectiveness (e.g., performance against low flying missiles is affected by moisture profile)
- AVMP supports determination of electro-magnetic (E-M) and electro-optic (E-O) propagation needed for a variety of United Stated Navy (USN) missions. E-O signals are inhibited by attenuation or reduction of the signal by atmospheric moisture.
- AVMP supports determination of contrail information needed to support effective use of stealth technologies.
- AVMP is needed to understand effectiveness of chemical and biological agents.
- AVMP is needed to factor in diurnal variations to tactical decision aids (refresh issue) for tactical missions.
- AVMP is needed to characterize the evaporation duct and is a very important factor in ship radar detection range.
- AVMP is required for support of Artillery and Tank Gunning operations to include projectile selection.

Safety of Operations

- AVMP supports determination of safety of flight during airfield/carrier operations for resource protection.

Crew and Site Preparation/Protection

- AVMP is needed to understand and predict effects to crew/personnel performance (when coupled with high temperatures and especially in closed vehicles or MOPP gear), equipment performance and maintenance as well as handling, storage and use of building materials. Accurate long-term forecasts of this parameter allow commanders to do more effective mission planning overall and specifically to better protect and prepare personnel and equipment for environmental conditions.

Climate

- AVMP is used in both weather and climate modeling efforts and is required at specified levels to be effective in improved models for both DOD and DOC (e.g., Numerical Weather Prediction (NWP) models, regional model for three-hour forecast).
- AVMP supports determination of clouds.

Instrumentation: Sounder (IR X-track)
Sounder (MW X-track)
Imager/Sounder (MW Conical)
Imager/Radiometer (VIS/IR/LL)

EDR: Atmospheric Vertical Temperature Profile (AVTP)

Definition: AVTP is a sampling of temperature at stated intervals throughout the atmosphere, including mesospheric scales.

Uses:

C^{4}I Systems Support

- AVTP is used to determine antenna site selection.
- AVTP is used to determine surface winds, which create radar background noises and affect stability of various antenna, thereby affecting communication.

Hazard Identification/Warnings

- AVTP supports determination of local and enroute METOC hazards to all Defense Transportation Systems.
- AVTP supports determination of E-O propagation need for detection of volcano alert, forest fires, oil spills, drought, and emission plumes.

Navigation/Trafficability

- AVTP is used in support of trafficability assessments since surface temperature affects soil drying, freezing and thawing which affects trafficability (including off-road movements, river crossing and bridges set up on frozen ground).

General Forecasting

- AVTP is used in both weather and climate modeling and efforts (including model results verification) and is required at specified levels to be effective in initialization and predictive performance of various models for both DOD and DOC (e.g., NWP models, regional model for three-hour forecast).
- Temperature information over the northeastern Pacific Ocean (only provided by a polar orbiter) is especially important since this area is turbulent and it influences air flows heading for the US.
- Medium-range forecasts, using AVTP as input, are important to the general public, to utility companies for shifting fuel and planning loading needs, and to construction firms for planning work schedules.
- Stratospheric satellite soundings are needed for model input. The model will not provide reliable results in the stratosphere after two days without satellite soundings.
- AVTP is used for assessment of wind shear/turbulence and precipitation.
- ATVP provides support to hurricane forecasting (with sea surface temperature information) since required information on atmospheric dynamics can be obtained from knowledge of this parameter.
- AVTP is used to determine river stage/flood forecasting.

- AVTP supports determination of clouds.

Weapon Systems Support

- AVTP is needed to understand effectiveness of chemical and biological agents. Some agents are more persistent at low temperatures. Vaporization may be a problem with higher temperatures. Normal atmospheric temperatures have little direct affect on a biological agent aerosol. Sub-freezing temperatures make water-based decontamination methods ineffective.
- AVTP supports determination of E-M and E-O propagation needed for a variety of USN missions. E-O signals are inhibited by temperature affecting atmospheric refraction near the surface and temperature contrast with the surrounding environment. Also, ice reduces E-M and E-O sensor effectiveness.
- AVTP is used to understand and predict radar effectiveness (e.g., performance against low flying missiles is affected by temperature profile).
- AVTP is used to determine weapons effectiveness, especially missiles. Hotter weather decreases missile maximum thrust (affecting time to target) and lift (increasing fuel consumption and narrowing the performance envelope).
- AVTP is needed to factor in diurnal variations to tactical decision aids (refresh issue) for tactical missions
- AVTP is needed to characterize the evaporation duct which is a very important factor in low altitude system performance.
- AVTP is used to derive surface winds, which affect weapon accuracy/ trajectory and agent dispersion.
- AVTP is used in all Army operations to include Attack/MLRS and Sense and Destroy Armor (SADARM).
- A GRC analysis showed that both windspeed and direction errors as well as temperature errors produce corresponding crossrange and downrange errors which equate to a reduced probability of acquisition of the target by the SADARM terminal sensor (i.e., temperature profile impacts on downrange error: with no wind error, for each one degree Kelvin temperature profile error, Pk is reduced by approximately 45% of its original value. This assumes that the 1 degree error is the average error over the flight path)

Safety of Operations

- AVTP is used to assess atmospheric icing potential to be made available to airfields (ice restricts airfield operations), aircraft carriers, and mission planning system to determine Go/No Go criteria, force composition and tactics. This icing can accumulate on wings and control surfaces of both manned and unmanned vehicles. If ice is drawn through engine intakes it can severely damage turbine blades resulting in loss of power and eventually shutting down the engine. In addition, very low temperatures can produce detectable ice-fog exhaust trails from various systems.
- AVTP is critical to understanding surface winds which affect air/flight safety, and visibility (e.g., smoke, debris, sand, snow).

Crew and Site Preparation/Protection

- AVTP is critical to understanding and prediction of effects to crew/personnel performance (when coupled with humidity and especially in closed vehicles or MOPP gear), equipment/electronics performance and maintenance, weapons performance as well as handling, storage and use of building materials. Accurate long-term forecasts of this parameter allow commanders to do more effective mission planning overall and specifically to better protect and prepare personnel and equipment for environmental conditions.

Instrumentation: Sounder (IR X-track)
Imager/Sounder (MW Conical)
Temperature Sounder (MW X-track)
Imager/Radiometer (VIS/IR/LL)

EDR: Imagery

Definition: Imagery is specialized cloud and ice imagery at sufficient resolution to enable analysts to discern of atmospheric phenomena--from cloud types (defined in Air Force Instruction (AFI) 15-111 Vol 1) and elements to planetary scale (10^7m) weather patterns.

Uses:

General Forecasting

- Imagery is used for visual (including visual night imagery), IR, and stratus/fog/snow discrimination at regional resolution. It is important to understand the amount of cloud cover, and ice and snow distribution in cloudless areas especially in data sparse regions where satellites provide the only information (e.g., Latin America, Arctic).
- Imagery is used to provide coastal fog and low-altitude forecasts at nine non-instrumented Alaskan mountain passes.
- Imagery is used to monitor and classify the land surface since the present methods (ground stations around the world) are cumbersome.
- Imagery is used to observe scale features associated with the beginning and during severe storms and flash floods in the western regions of the US (horizontal spatial resolution (HSR) of 1 km at nadir is essential).
- Imagery is required for improvement in hurricane forecasts with coverage within 100km of the storm and within 2000km of the storm and location of tropical cyclones.
- Imagery is necessary for short range/short-notice forecasts in support of national and international contingencies (e.g., disaster relief or rescue missions).
- Imagery supports determination by Air Control Center staff of current weather conditions over target areas for missions currently being planned. This allows for last minute changes in mission execution, based on weather conditions, thereby, improving mission effectiveness.
- Internationally, imagery is used to inventory forests.
- Ice edge and concentration data derived from satellite imagery are used in meteorological and ice drift models for operational forecasting.

Ice/Ocean Analysis

- Imagery is used to characterize sea/freshwater ice properties, including ice edge location, concentration, thickness, and size of leads/polynyas.
- Imagery supports production of National Ice Center’s (NIC’s) ice products (imagery is the main source of this data).
- Ice edge information is used by the fishing industry.
- Imagery supports global and regional ice analyses and forecasts that are used by the Coast Guard and shipping industry to advise ships that are transmitting near or in the ice pack.

Weapon Systems Support

- Imagery supports analysis of weather on the horizontal (1 km/global, 0.4 regional) and temporal scales that have significant impact on mission planning, aircraft operation, weapon delivery/loadout and battle damage assessment . The 4 hour refresh requirement is required to adequately represent the time scale of weather that has the most significant impact on Carrier Strike, amphibious and special warfare operations.

Safety of Operations

- Imagery supports determination of incoming weather systems and their severity in support of base and flight operations such as reconnaissance and refueling.
- The detail necessary in ice forecasts to protect against ship destruction and related consequences requires 1 km HSR.

C^4I Systems Support

- Ocean color imagery supports analysis of ocean fronts and eddies and supports sonar operations and anti-submarine warfare (ASW).

Hazard Identification/Warnings

- This EDR is used to estimate turbulence in lee of mountainous areas.
- Imagery is used to provide an estimate of ice melt inception that is used in hydrological estimates of potential flooding conditions.
- Imagery is used for forest fire surveillance.

Navigation/Trafficability

- Imagery defines areas where trafficability could be a problem for military vehicles.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW/Conical)

EDR: Sea Surface Temperature (SST)

Definition: SST is the temperature of the surface layer of the ocean (high resolution, all weather).

Uses:

C^4I Systems Support

- SST supports forecasts/assessment of acoustics and sonar performance to support USN operations and decisions.
- SST supports prediction of radar performance against low-flying anti-ship cruise missiles within a specific range.

Ice/Ocean Analysis

- SST is used to direct Coast Guard surveillance aircraft in search for illegal foreign fishing activities since differences in ocean temperature provide indications of fish location.
- SST is used to directly evaluate the effects of ocean thermal conditions on fish stocks.
- SST supports various oceanographic analyses/services that are relevant to coastal circulation, tide and current predictions, water level, and hydrology. Products support coastal environmental management and monitoring activities of NOAA. The CoastWatch program products support protection of endangered species, regulation of fisheries, red tide assessments to name a few. The 1 km resolution is required to accurately represent the many small coastal features.

Navigation/Trafficability

- SST is used to map location of the Gulf Stream which is important for ship routing (use/avoidance of GS can save fuel on long voyages).
- SST supports production of tactical ice analyses showing ice edge position, ice concentration, thickness, age, and direction of drift to ensure safety of navigation as well as to locate and identify the presence of icebergs and ice islands.

General Forecasting

- SST is used in the determination of long-range weather forecasts and climactic variability due to SST changes (esp. in the tropical Pacific).
- SST provides daily boundary conditions for forecast models.

Climate/Atmospheric Monitoring

- Analyses, as describe above under ocean/ice analysis, are relevant to global change monitoring and ocean and climate research

Weapon Systems Support

- SST supports characterization of the evaporation duct which affects low-altitude system performance.
- SST bounds detection and accuracy parameters for emerging shallow water ASW systems (specific resolution and accuracy are needed).
- SST supports characterization of radar clutter conditions to support prediction of sea-skimming missile behavior.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Imager/Sounder (MW Conical)

EDR: Sea Surface Winds (SSW)

Definition: SSW is measurement of atmospheric wind speed/direction at the sea/atmosphere interface.

Uses:

General Forecasting

- SSW supports initialization/validation of various current and soon to be improved future models (e.g., wave and circulation models, global/ regional data assimilation systems).
- SSW supports determination of short-term warnings and forecasts especially for severe and tropical storms. Vertical profiles of wind are very important to global observations. The mesoscale weather research program requires profiles both above and below the boundary layer to gain understanding of the environment in which severe storms generate. In non-precipitation conditions this EDR is used for front identification and location (wind sheers), identification of low pressure areas (location and intensity) and rapidly changing pressure systems and identification of the intertropical convergence zone. Refresh rates are six hours to meet tropical storm fixing requirements.

Weapon Systems Support

- SSW supports military mission planning activities specifically by determination of tail winds that affect the ground speed of specific missiles which affect time on target.
- Specific SSW attributes are required to provide wind and wave data to support understanding of precision guided missile (PGM) usefulness (there are critical/ narrow value for PGMs).
- A GRC analysis showed that both windspeed and direction errors as well as temperature errors produce corresponding crossrange and downrange errors which equate to a reduced probability of acquisition of the target by the SADARM terminal sensor. The slope of the Pk reduction curve is approximately a loss of 0.72% per meter displacement. At a little more than 65 meters, Pk is half of its original value. At a 50% cut in Pk, twice as many shell will be needed to achieve a kill)

Safety of Operations

- Winds affect wave and surf conditions and therefore, affect the determination of the safety of ships and personnel landing. In addition winds affect the ability to move aircraft on carriers and can cause damage to topside gear including antennas.
- Specific SSW attributes are required to provide wind and wave data to support understanding of potential harm to amphibious landing craft operations, naval facilities located in low lying coastal areas and all harbor areas along a coast, (i.e., hurricane/ flooding) and aircraft carrier flight operations (aircraft safety and recovery).

Hazard Identification/Warnings

- Surface wind drift information is critical in determining the trajectory of "red tide" organisms and other potentially environmentally damaging material.
- Access to accurate real-time marine winds are crucial to the National Ocean Service (NOS) hazardous materials spill responsibilities.
- Specific SSW attributes are required to provide wind and wave data to support understanding of potential harm to naval facilities located in low lying coastal areas (i.e., hurricane/flooding)

Ice/Ocean Analysis

- SSW supports CoastWatch requirements.
- Surface winds provide a valuable aid for forecasting yields of certain marine species dependent upon transport for spawning.

Climate/Atmospheric Monitoring

- SSW supports climate studies.
- Wind stress is one of the primary ocean forcing functions and a sensitive measure of air-sea interaction. SSW speed is needed because it is a fundamental input parameter for estimating the surface fluxes of heat, water vapor and wind stress via bulk formulas. One example is the effects of Amazon deforestation on rainfall in that region.

Instrumentation: Imager/Sounder (MW Conical)

EDR: Soil Moisture (SM)

Definition: This EDR is moisture in the soil within the zone of aeration, including water vapor present in soil pores.

Uses:

Navigation/Trafficability

- SM supports assessment of the movement ability of tactical vehicles which contribute to the intelligence preparation on the battlefield. Moisture at various levels impacts surface traction, cross country vehicle speed and trafficability as well as mine placement/detection.
- SM is essential for obstacle breaching and crossing.
- SM is essential for risk forecasting.
- A GRC study showed that errors in the soil moisture forecast can impact troop planning, movement, and potential casualty levels as a result of not establishing sufficiently high force levels to compensate for the soil moisture conditions. The results of the model show that as forecast error for soil moisture increases (and the soil is predicted wetter than it actually is), the percentage of forces predicted to be model decreases. If this soil moisture prediction were used to forecast enemy troop movements, the enemy would arrive earlier and with more forces than predicted.

Weapon Systems Support

- SM supports derivation of optical and infrared characteristics of the earth's surface for E-O weapon systems support (target/background contrast). Specific attribute levels are important for this support.

General Forecasting

- SM supports characterization of surface moisture for model initialization. Short term rain variability demands 8 hour refresh to avoid false characterization.
- SM provides initialization of, input to and validation of various model (including NWP models) results. SM supports calculation of energy fluxes at the surface (NCEP Eta Model), providing feedback on precipitation, determining microscale weather features, and determining the mesoscale environment for severe storm development. Soil moisture is an essential input for the mesoscale models used to predict weather conditions over the battlefield.
- SM is used as an aid for flood forecasting and runoff assessments.
- SM is an input to Army stream flow analysis (used for river crossing, dam volume capacity and Agricultural Meteorological models).

Instrumentation: Imager/Radiometer (VIS/IR/LL)

Imager/Sounder (MW Conical)

Atmospheric Parameters

EDR: Aerosol Optical Thickness

Definition: This parameter represents vertical visibility.

Measurement: Measurements of aerosol optical thickness are severely impacted by low solar illumination angle.

Uses:

General Forecasting

- This EDR is used for correcting errors in SST and vegetation index products and possible atmospheric temperature soundings.

Climate/Atmospheric Monitoring

- Aerosol Optical Thickness is an important radiative forcing component affecting climate. Less than 2 daytime observations creates a loss of information about growth of particles with time as a function of humidity, which gives an indication of how “water-like” the particles behave. If the range doesn’t go down to 0.0 but stops at 0.1, over half the earth will go unmeasured.
- Anthropogenic aerosols cause a clear-sky climatic forcing that is estimated to be comparable in magnitude to the forcing by anthropogenic greenhouse gases and therefore must be measured.

Weapon Systems Support

- This EDR is used in battlefield visibility models and to determine target signature contrast which in turn determines lock-on range.

Note: Given the relationship to SST, this EDR has some similar uses/impacts described under each of this EDRs (e.g., impact to ice analyses as discussed under SST).

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Aerosol Particle Size

Definition: This parameter is the measurement of size of aerosols comprising aerosol concentration.

Measurement: Measurements of aerosol particle size are severely impacted by low solar illumination angle.

Uses:

General Forecasting

- Aerosol Particle Size is used in estimating the wavelength dependence of optical thickness, related to the physical size of the particles, to understand and correct for the affects of aerosol attenuation in the infrared (depends on the accuracy and precision). If less precision is provided, observations will have to be averaged, increasing the spatial resolution of the parameters being corrected (e.g., SST). If less accuracy is provided, then the errors in the corrected infrared or visible radiances may be too large to meet user requirements for SST, vegetation index and temperature soundings.

Climate/Atmospheric Monitoring

- This EDR is used to understand the net radiative effect of volcanic aerosol particles. If they are small, then the volcanic aerosol will cool the Earth's surface. If they are large then they will warm it.
- Aerosol Particle Size characterizes the stratospheric aerosol layer. If sensing depth is limited to 15 km, then no information about stratospheric aerosols would be observed. Since volcanic eruptions can greatly affect the stratospheric aerosol layer, which in turn can greatly affect the accuracy of SSTs, sensing depth is needed to at least 30km. If we have less than 2 daytime observations per day, we lose information about the growth of particles with time as a function of humidity which, gives an indication of how "water-like" the particles behave.
- This EDR is used to understand atmospheric illumination
- Anthropogenic aerosols cause a clear-sky climatic forcing that is estimated to be comparable in magnitude to the forcing by anthropogenic greenhouse gases and therefore must be measured.

Hazard Identification/Warnings

- This EDR is required for detection of volcano plumes/ash clouds, forest fires, oil spills, drought and emission plumes.

  Note1: Since this EDR is tied to SST and other parameters it has some similar uses/impacts described under each of these EDRs (e.g., impact to ice/icing analyses as discussed under SST).

  Note2: If the EDR is not estimated over the desired range this parameter can't be used.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Ozone Column/Profile

Definition: This EDR is a measurement of ozone concentration within a specified volume.

Measurement: Measurement of ozone is baselined for the 1330 NPOESS orbit because high solar illumination is required to monitor the solar backscatter signal and to provide data continuity with earlier mapping products.

Uses:

Climate/Atmospheric Monitoring

- This EDR is used to consistently and continuously detect and monitor global ozone depletion trends and increases in other influential trace gases as a result of industrial activities as well as the stability of the stratospheric ozone layer.
- This EDR is used to understand impact of ozone to global change. Monitoring of ozone has assumed increased importance. Ozone analyses are largely in support of climate studies, therefore, long term trends are of paramount. Ozone depletion (e.g., above Antarctica) remains one of the most critical global environmental problems facing humankind today.
- This EDR is used to understand ozone's contribution to the greenhouse effect. Ozone is present in many layers of the atmosphere. The importance of the stratospheric ozone layer is in shielding the Earth from incoming UV radiation. More recently, an increase in ozone in the troposphere has been thought to contribute to the greenhouse effect and is of concern due to its pollutant effects.
- Ozone filters UVB radiation. UVB radiation can cause skin cancer. Loss of ozone results in higher results in higher incidences of skin cancer.

Hazard Identification/Warnings

- Ozone measurement is a critical component in the detection of volcano alerts, forest fires, oil spills, drought and emission plumes.

Instrumentation: Ozone Monitor (SSTP)

EDR: Precipitable Water

Definition: This EDR represents the total atmospheric water vapor contained in a vertical column of unit cross-sectional area between any two specified levels. Units are millimeters of condensed vapor.

Uses:

Climate/Atmospheric Monitoring

- Precipitable water is important to studying the radiative balance of the atmosphere. Precipitable water along with cloud top height, cloud cover, and liquid water is crucial to climate studies particularly those focused on the radiative balance of the atmosphere.

General Forecasting

- This EDR is an essential component for NWP, short-term weather forecasting and climate analysis and it complements AVMP.

Instrumentation: Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Precipitation Type/Rate

Definition: The parameter measures the rate of precipitation in mm/hour and identifies the precipitation as rain, cloud, water or ice.

Uses:

Weapon Systems Support

- This EDR is needed as input information for acoustic noise level determination (needed for ASW), cloud determination (needed from strike launch/recovery), and E-M and E-O propagation (needed for target identification).
- Knowledge of rain is necessary because rain has impact on the guidance/range/delivery of specific weapon systems and because vertical visibility is crucial for proper correlation of optical correlation systems.
- Rain and snow can affect explosives (can cause predetonation of munitions).
- Precipitation affects specific chemical agents (persistence, neutralization, decontamination).
- Rain can attenuate extremely high frequency communications systems and radar system range.

Safety of Operations

- Knowledge of ice is necessary for those ice analyses discussed for AVTP (e.g., flight safety).
- Antenna icing creates a potential capsizing threat due to topside ice weight.
- Rain and snow can degrade missions/mission planning due to its negative impact on visibility and air operations including paradrop.

General Forecasting

- Precipitation is a factor in determining the general weather conditions and the current weather forecast within an area of operations.
- This EDR is used to validate and initialize weather forecasting and climate models. Numerical forecast models use precipitation data to determine the latent heat released due to moisture condensation (this helps to drive global circulation). Instantaneous rain rates can vary enormously (1-30 mm/hour). These rain rates must be measured globally with specific accuracies for use in climate analysis, weather forecasting, and agricultural/hydrological applications. Less direct measurements (vs. rain gauges) from satellite instruments are needed over rural areas, mountainous areas and over the oceans.

C^{4}I Systems Support

- Rain and snow can degrade missions/mission planning due to its negative impact on communications, surveillance systems (e.g., rain decreases radar range and attenuates radar signals and therefore hostile forces could hide in or be masked by precipitation to avoid radar detection), and photographic and infrared collection systems.

Climate/Atmospheric Monitoring

- Precipitation is a key variable in monitoring the Earth's climate system (accuracy is key and a key component of the Earth's hydrologic cycle).
- Precipitation is needed for analysis of synoptic-scale weather features, such as fronts and tropical cyclones, and for evidence of isolated or scattered showers or thunderstorm activity.

Navigation/Trafficability

- Rain and snow can degrade missions/mission planning due to its negative impact on visibility and trafficability/troop mobility. For trafficability specifically, remote sensing of precipitation is essential for terrain analysis since networks of surface precipitation gauges are not feasible on the battlefield. High rainfall rates influence river currents, water depth, and bridging operations. It complicates other construction or maintenance jobs, affects flooding, river crossings, stream flow, and soil bearing strength.

Hazard Identification/Warnings

- Precipitation estimates are necessary to define areas where flash floods are likely to occur.

Instrumentation: Imager/Sounder (MW Conical)
Sounder (IR X-track)
Imager/Radiometer (VIS/IR/LL)

EDR: Pressure (Surface/Profile)

Definition: This parameter is the measurement of pressure at surface and profile.

Uses:

Weapon Systems Support

- Air pressure affects projectile, barofuzing and fire control calculations. The density of the air affects gunnery computations and ballistic performance, essential for projectile selection.
- Pressure is used as input information for cloud and E-M/E-O determination in support of various military missions such as ASW detection/prosecution.
- Pressure is used for weapons planning (speed/time on target, accuracy, trajectory) and agent dispersion.
- Pressure supports characterization of the evaporation duct which is a very important factor in low-altitude system performance.

General Forecasting

- This EDR supports determination of wind shear/turbulence,
- This EDR supports calculation of refractivity that affects signal propagation
- This EDR supports determination of low-level and upper-air wind.
- This EDR helps determine altimeter settings and density altitude.

Safety of Operations

- Since this EDR is important to understanding winds, it affects operations safety. High winds create problems with air/flight safety (including fuel consumption), watercraft safety, river crossings, and visibility (e.g., smoke, debris, sand, snow).
- This EDR affects paradrop operations.

C^4I Systems Support

- Since this information is important to understand winds it affects communications. Surface winds create radar background noises and affect stability of various antenna and therefore communication and detection systems.
- Pressure is a required input to antenna siting calculations.

Navigation/Trafficability.

- Because this EDR helps in the forecast of surface winds, it affects trafficability forecasts. Surface winds contribute to trafficability of soil since they cause moisture to evaporate.

Crew and Site Preparation/Protection

- As this EDR applies to surface winds it affects crew/site preparation. Advanced knowledge of winds (and associated "debris") allows for effective planning and for protection of resources. Winds also affect construction activities.

Hazard Identification/Warnings

- Pressure supports determination of the intensity and path of major weather storms.
- Pressure data (hence wind forecasts) impact volcanic ash cloud movement, forest fire growth, oil spills, drought and emission plumes.

Instrumentation: Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Suspended Matter

Definition: Detection of suspended dust, sand, and volcanic ash (sea salt as objective).

Measurement: The visible signature of atmospheric matter is severely impacted by low solar illumination angle.

Uses:

Climate/Atmospheric Monitoring

- This EDR is used to monitor volcanic ash plumes.

Hazard Identification/Warnings

- This EDR is used to issue aviation warning to reroute flights around suspended matter plumes.
- Surface visibility is affected by dust.

Weapon Systems Support

- E-O lock-on range is affected by dust.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Total Water Content

Definition: The measure of moisture in a given volume of the atmosphere.

Uses:

General Forecasting

- Total Water Content is used to forecast precipitation amounts.

Weapon Systems Support

- This EDR is used as an input to tactical decision aids.

Safety of Operations

- This EDR supports identification, analysis, and forecast of conditions that can cause air frame icing and contrail formation.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

Cloud Parameters

EDR: Cloud Base Height

Definition: Height above the ground where cloud bases occur, from surface to 30 km.

Uses:

Safety of Operations

- This EDR provides aviation-related forecasts. Flight minimums exist for both take-off and landing (military and civilian aircraft). The height of the lowest cloud layer is of direct interest. Icing and turbulence levels are associated with cloud bases for clouds at appropriate heights. Base heights must be known accurately and at high vertical resolution for both icing and flight minimums.
- Derivation of ceiling height is key to military pilots since it is used to make decisions on maneuvers for all flight levels.
- This EDR is used for Visual Flight Rules (VFR) planning and conducting VFR operations. This is dependent upon ceiling. Alternate airport/landing designation is dependent on ceiling height, and ceiling is used to determine whether an alternate airport has to be selected.
- The heights of the bases and tops of cloud layers are used to determine paratroop drop heights.
- Knowledge of this EDR supports aircraft detection/ identification location of facilities and personnel safety (area of operations), as well as assessment of the cover and concealment situation.

Weapon Systems Support

- The heights of the bases and tops of cloud layers are of use in a number of military planning and operational situations including selection of maneuvers for air-to-ground weapons delivery.
- Knowledge of this EDR supports assessment of impact to target acquisitions and agent deployment.
- This EDR is used for weapons/projectile selection.
- This EDR supports stand-off range determination.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Cloud Cover/Layers

Definition: Cloud cover is the fraction of a given area that is overlaid in the local normal direction by clouds; it is the portion of the earth's horizontal surface that is masked by the vertical projection of clouds. It needs to be known at separate and distinct levels.

Uses:

Climate/Atmospheric Monitoring

- Two types of climatology studies are supported by cloud cover data. The first is general frequency of occurrence statistical analysis to support a variety of uses such as military mission planning and global albedo assessment. The second and most stressing use is for global budget studies. Cloud cover is the main variable component in determining the amount of energy absorbed by the atmosphere, and in long wave emission by the earth-atmosphere system. The amount of cloud cover is the major determinant in the amount of sunlight reaching the surface and in the UV level at the surface (forecasts).
- Cloud cover (along with cloud top height, liquid water and precipitable water) is crucial to climate studies particularly those focused on radiative balance of the atmosphere.

Weapon Systems Support

- This EDR is used to assess the cloud free line of sight between aircraft and targets on the ground and to predict the success of aerial reconnaissance.
- Type/amount of cloud cover presents either favorable or unfavorable to conditions for specific agent transport and dispersion, for use of PGMs for air-to-ground attack and to assess E-O weapons utility.
- Low/overcast skies limit the effectiveness of aerial illumination devices, degrades visual target acquisition and tracking (limits heating of inactive targets and lowers target detection ranges for thermal sightings), degrades close air support and aerial resupply missions, reduces effectiveness of infrared and photographic collection systems, affects agent deployment, and may restrict the use of unmanned aerial vehicles (UAVs).
- Low clouds improve special forces mobility due to the decreased chance of detection but may degrade E-O system employment/target acquisition.
- A GRC study found (in summary) that the cost per target destroyed varies substantially by location and is driven by Pk, mission timeliness and weather (cloud cover, ceiling, visibility) forecasting capability. It was also determined that cost-per-target destroyed can be reduced in all locations if the above mentioned forecasts can be made more accurately. The reason for these savings is that improved forecasts

result in missions not being assigned in areas where aircraft and/or weapon target acquisition systems are degraded. Additional sorties into threat areas results in increased probability of losses to friendly forces. That is to say, improved forecasts save lives, fuel, weapons, and aircraft.

General Forecasting

- Higher resolution contributes to accurate cloud cover determination for small cumulus, which are especially prevalent in the tropics.
- This EDR is used to determine cloud movement and development.
- This EDR is used to determine ceiling height.

Navigation/Trafficability.

- Cloud cover affects incoming solar radiation which, in turn, affects the drying of soils.

Safety of Operations

- Knowledge of this EDR supports aircraft detection/ identification location of facilities and personnel safety (area of operations), as well as assessment of the cover and concealment situation.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Cloud Effective Particle Size

Definition: This parameter is the area-averaged measure of cloud particle size, derived from imagery (with the aid of radiative transfer calculations); it must be retrieved by cloud type.

Uses:

Climate/Atmospheric Monitoring
- This EDR is key to study support including climate, global radiation budget, water budget, cloud radiative forcing and cloud modeling.

General Forecasting
- This EDR supports estimation of liquid water path (in conjunction with optical depth).
- Improving skill in forecasting aircraft icing depends on this EDR.
- This EDR aids the forecaster in judging the collection efficiency of the aircraft surfaces to supercooled water droplets in both stratiform and cumuliform clouds.
- This EDR aids in the forecast of rime versus clear icing.

Safety of Operations
- This EDR is an important element of the enroute data segment of the flight weather briefing package.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)

EDR: Cloud Ice Water Path

Definition: This EDR is a measure of the equivalent water mass of the ice particles in a unit vertical column through the cloud. Measured information must be sensitive to the number of particles, their sizes, and their densities.

Uses:

Climate/Atmospheric Monitoring

- This EDR is used in global climate studies.

Safety of Operations

- This EDR supports determination of contrail formation.

Instrumentation: Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Cloud Liquid Water

Definition: This EDR is the measurement of the water equivalent within clouds.

Uses:

Climate/Atmospheric Monitoring

- Cloud Liquid Water is needed to understand the interactions between radiation and clouds.
- This EDR is a critical input to climate studies particularly those focused on radiative balance of the atmosphere.

Weapon Systems Support

- With appropriate assumptions, this parameter may be related to cloud optical thickness which is key to E-O weapons effectiveness.

Instrumentation: Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Cloud Optical Depth/Transmittance

Definition: This parameter is the measurement of cloud optical thickness and emissivity in the visible and IR portions of the spectrum.

Uses:

Weapon Systems Support

- This EDR supports assessment of the performance of any of several weapon and sensor systems which can see through partially transparent clouds. These are supported by a variety of tactical decision aids which predict weapon performance based on input weather parameters.

Climate/Atmospheric Monitoring

- This is the most important cloud optical property that permits determination of the cloud radiative effects on global radiation and heat balance (i.e., determines how much solar energy passes through to ground/sea).

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)

EDR: Cloud Top Height

Definition: This EDR measures cloud top height.

Uses: Climate/Atmospheric Monitoring

- This EDR supports global energy budget studies to indicate the level of the atmosphere where incoming radiation is reflected and/or outgoing radiation is blocked.
- This EDR supports climate studies particularly focused on the radiative balance of the atmosphere.

General Forecasting

- Cloud Top Height supports forecasts of severe weather (including severity of storms for mesoscale research activities and for radiation studies). Cloud top height is indicative of the updraft velocity and of the maturity of the convective storm system.
- This EDR aids the forecaster in predicting rime and mixed icing in stratiform clouds from 3,000-6,000 feet and clear or mixed icing in cumuliform clouds from 3,000-20,000 feet.

Safety of Operations

- This EDR supports aviation planning by supporting forecast of icing. Derivation of ceiling height is key to military pilots since it is used to make decisions on all flight levels. It provides the information to forecast icing based on an understanding of the thickness of the layer in which icing conditions occur (cloud top height gives an upper bound for this layer).
- Cloud Top Height supports forecast of turbulence which is used to determine optimum paratroop drop heights.
- This EDR is an important element of the enroute data segment of the flight weather briefing package.
- Knowledge of this EDR supports aircraft detection/identification location of facilities and personnel safety (area of operations), as well as assessment of the cover and concealment situation.

Weapon Systems Support

- This EDR supports selection of maneuvers for air-to-ground weapons delivery.
- This EDR supports understanding impact to target acquisition and agent deployment.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Temperature Sounder (MW X-track)

Imager/Sounder (MW Conical)

EDR: Cloud Top Pressure

Definition: This parameter is the derived pressure at cloud tops.

Uses: General Forecasting

- This parameter is an input to forecast and climate models.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Cloud Top Temperature

Definition: This EDR measures the temperature at the cloud tops.

Uses: General Forecasting

- This EDR supports operational forecasting.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

Earth Radiation Budget (ERB) Parameters

EDR: Albedo

Definition: This EDR measures the ratio of the amount of the visible spectrum electromagnetic radiation reflected by the Earth to the amount incident upon it.

Measurement: Measurements of albedo are severely impacted by low solar illumination angle and the 1330 NPOESS orbit is the primary orbit for making this measurement.

Uses:

Weapon Systems Support

- This EDR is used to calculate the contrast between target and background for E-O weapon support.

Climate/Atmospheric Monitoring

- Albedo is related to global warming trends and is an input to climate models. As global warming causes loss of sea ice (an hence loss of a reflective surface) more heat can be absorbed by the oceans, enhancing global temperature rise).

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Downward Longwave Radiation (DLR) (Surface)

Definition: This EDR measures the downward longwave radiation at the surface or the amount of radiation emitted from the earth.

Measurement: Measurements of DLR are required from the 1330 NPOESS orbit to support NOAA/NASA data continuity with EOS CERES.

Uses:

Climate/Atmospheric Monitoring

- DLR is used to understand the processes by which the atmosphere, land, and oceans transfer energy to achieve global radiative equilibrium which in turn is necessary to simulate and predict climate.
- DLR is used for climate monitoring and prediction studies. In particular, this EDR will be used in the initialization of the radiation and cloud fields of the operational medium range forecast model, as well as the verification of forecast cloud and radiation fields.
- This EDR supports monitoring of regional anomalies (precision is key).
- DLR is used to demonstrate impact in monitoring studies (measurement accuracy and refresh are at the acceptable minimums).

General Forecasting

- This EDR support assessments of tropical rainfall estimates (outgoing longwave radiation histograms).
- DLR is an input to NWP models (HSR is key)

Instrumentation: Radiometer (CERES)

EDR: Insolation

Definition: This EDR measures absorbed solar radiation or the amount of solar energy absorbed by the Earth-atmosphere system (daily averaged estimate), measured at the Earth's surface.

Measurement: Measurements of surface insolation are required from the 1330 NPOESS orbit to support NOAA/NASA data continuity with EOS CERES.

Uses: Climate/Atmospheric Monitoring

- Insolation is the primary source of energy to the surface and drives surface fluxes of water vapor and sensible heat. It is used to understand the processes by which the atmosphere, land, and oceans transfer energy to achieve global radiative equilibrium which in turn is necessary to simulate and predict climate.

General Forecasting

- This EDR is an input to soil moisture, snowmelt and crop models. Specific attribute levels are required to run an off-line global soil moisture model that approximates a current state-of-the art regional model (NCEP Eta model).

Instrumentation: Radiometer (CERES)

EDR: Net Shortwave Radiation (TOA)

Definition: This EDR measures incoming shortwave radiation.

Measurement: Measurements of net shortwave radiation are required from the 1330 NPOESS orbit to support NOAA/NASA data continuity with EOS CERES.

Uses:

Climate/Atmospheric Monitoring

- This EDR is a key component for monitoring the current state and variability of the climate system.
- Imprecise net shortwave radiation estimates impact sea surface temperature prediction leading to climate change misestimates such as El Nino.

General Forecasting

- This EDR is important in validating the performance of models in forecasting on time scales from seasonal to long-term as well as in the initialization of future global forecast models. Less accuracy, than stated in the IORD will decrease the ability to accurately determine the atmospheric energetics and, therefore, our understanding of the dynamics of climate.

Instrumentation: Radiometer (CERES)
Spectrometer (ACRIM)

EDR: Solar Irradiance

Definition: Incident radiation measurements (total and 2 narrow bands)

Measurement: NPOESS measurements of solar irradiance are baselined for the 0530 orbit to accommodate the IORD-I threshold requirements for a 20 minute stare each orbit and for spacecraft accommodation reasons.

Uses: Climate/Atmospheric Monitoring

- This EDR supports monitoring of the total and spectral solar irradiance for determining solar influence on global change. Solar variability can influence global surface temperatures and middle atmosphere ozone concentrations. A continuous record (reliable, over many decades) of the variable energy input that reaches the Earth from the Sun is required. Solar UV variations in the 200-300 nm range, which is absorbed by the Earth's atmosphere, is necessary to fully assess long-term variations and are used to monitor the radiation primarily responsible for ionizing the Earth's upper atmosphere. Measurements in the 1.5 micrometer region are required because of its absorption by water vapor and its role in cloud processes. The 1.5 micrometer measurement also provides a measure of sunspot occurrences for interpreting the solar irradiance measurements.

Safety of Operations

- After precipitation, amount of cloud cover and soar irradiance hitting the ground affects evaporation of standing water and hence soil moisture. Misestimating soil moisture impacts trafficability estimates.

Instrumentation: Spectrometer (ACRIM)

EDR: Total Longwave Radiation (TOA)

Definition: This EDR measures outgoing longwave radiation.

Measurement: Measurements of total longwave radiation are baselined for the 1330 NPOESS orbit to support NOAA/NASA data continuity with EOS CERES.

Uses:

Climate/Atmospheric Monitoring

- This EDR is used to monitor variations in tropical precipitation in areas where few conventional precipitation measurements exist (e.g., rain gauges).
- This EDR supports national and international climate monitoring and diagnostic research.
- Climate monitoring, much more than weather observing, places requirements of long-term stability and comparability on satellite measurements for this EDR.
- This EDR is used to monitor seasonal and interannual climate variations (NWS).

General Forecasting

- Research is in progress to assimilate precipitation estimated from this EDR into the NWS/NCEP global model which may substantially improve global forecasts of precipitation.
- This EDR is used in initiating Numerical Weather Prediction models (40 km grid)

Weapon Systems Support

- As it supports estimation of precipitation, this EDR helps assess the impact on availability to use radar guided and E-O/IR weapons.

Safety of Operations

- As it supports estimation of precipitation, this EDR helps assess soil trafficability.

Note1: If less performance is provided than needed, all of the above stated functions will suffer.

Note 2: This EDR is the only independent source for crucial information that is needed in real-time.

Note 3: If this data is not available as required, the ability to monitor and forecast significant climate anomalies, such as ENSO warm and cold episodes, would be impaired.

Instrumentation: Radiometer (CERES)
Spectrometer (ACRIM)

Land Parameters

EDR: Land Surface Temperature

Definition: This EDR measures the skin temperature of the uppermost layer of the land surface.

Uses:

Weapon Systems Support

- Land Surface Temperature is needed to characterize backgrounds for E-O systems and is used in infrared cloud/no cloud decision for processed cloud data.
- Vertical atmospheric density profiles, determined by this EDR, impact artillery.

Climate/Atmospheric Monitoring

- The land surface temperature has a strong influence on the surface radiation budget, on the transfer of heat and moisture to the atmosphere and on surface hydrology/soil moisture. This EDR is used to establish the temperature structure of the lower atmosphere.

Navigation/Trafficability

- This EDR allows understanding of freeze and thaw determination, as well as evapotranspiration, and, therefore, supports ground trafficability forecasts for the Army.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

EDR: Normalized Difference Vegetation Index (NDVI)

Definition: This EDR is the measure of biomass greenness in NDVI units.

Measurement: This measurement is severely impacted by low solar illumination angle the 1330 NPOESS and 0930 METOP orbits are the primary sources of this data.

Uses:

Climate/Atmospheric Monitoring

- NDVI is a starting point for monitoring surface conditions such as drought on a global scale.
- NDVI is potential indicator of climate change or desertification.

General Forecasting

- NDVI is used as an input to algorithms for estimating LAI and vegetation fraction.
- NDVI aids in production of soil moisture fields and estimates of surface roughness.
- NDVI is used as input to numerical prediction models.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Snow Cover/Depth

Definition: This parameter measures the horizontal and vertical extent of snow cover.

Uses:

Navigation/Trafficability

- Snow Cover/Depth is used to support the intelligence preparation of the battlefield. It is used to support mobility/countermobility planning by determining trafficability and movement rates for infantry, mechanized infantry, armor, and cavalry for off-road mobility of both friendly and enemy forces. An overlay of snowfall accumulated on the ground is electronically sent to the digital terrain support system and maneuver brigades for infantry activities.

Weapon Systems Support

- Snow depth is used for mine emplacement and effectiveness as well as remote sensing of mines.
- This EDR provides input to E-O target background/contrast and provides missile system support. Snow changes features and contrasts and when it melts leaves patches that become new features in the image.

Safety of Operations

- This EDR is used to assess river stage/flood forecasting (due to snow/ice melt), soil moisture, frost, and determination of the stability of bridge structures.

Crew and Site Preparation/Protection

- This EDR is used to understand limits to cable installation/maintenance.
- This EDR is used to choose construction equipment for a particular site.

General Forecasting

- The NWS uses this parameter to complete flood forecasts, spring flood outlooks and water supply forecasts. Accurate estimates are critical to the quality of hydrologic products throughout the country where snow cover is a significant hydrometeorological parameter. Recent studies have indicated that improved estimates of snow water equivalent over the Western US can save hundreds of millions of dollars in hydrologic projects involving hydropower generation, agriculture, and domestic water supply uses.
- NWP models requires input of the presence of snow at high accuracy.

Climate/Atmospheric Monitoring

- Snow cover extent is used for albedo determinations in climate studies.
- Snow and ice are significant because their formation and disappearance involve large transfers of latent heat. They have major effects on turbulent heat transfer from underlying land or water to the atmosphere.

Ice/Ocean Analysis

- Snow cover moisture equivalent data are used in water resource studies.
- Snow cover is used in support of marine resources research.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

EDR: Vegetation Index/Surface Type

Definition: This EDR specifies the predominant vegetation type in a given area, coupled with type of soil. There are 21types of vegetation to be measured: crop land, brush/scrub, coniferous forest, deciduous forest, tropical forest, grass land, swamp, marsh/bog, flooded land, loam, sandy soil, clay, peat, desert, water, snow/ice, urban/ developed, rocky fields, tundra, and Savannah.

Uses:

<u>Weapon Systems Support</u>

- Vegetation and surface type are required as boundary conditions for infrared and microwave weapon systems support.

<u>Climate/Atmospheric Monitoring</u>

- This EDR supports determination of surface emissivity (dependent on type of vegetation).

<u>General Forecasting</u>

- This parameter is required as input to the agricultural analysis model supporting various U.S. Government customers and to EOTDA forecast models used by all services.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

Ocean/Water Parameters

EDR: Currents (near-shore, surface)

Definition: This EDR measures large-scale movements of the surface waters of the ocean driven by wind and the distribution of water density. Currents are a vector quantity with both speed and direction.

Uses:

Safety of Operations

- Currents information is used to produce tactical scale ice analyses (e.g., direction of drift) for navigation safety (prevent vessel accidents) and to locate/identify icebergs/ice islands in the polar regions.
- This EDR is used in coast and landing beach analyses for amphibious assault operations.
- This EDR is used to determine the characteristics of the river for riverine operations.
- Infiltration and exfiltration route planners and global mission planning must consider timing and height of tides. Infiltration at low tides results in more exposure while moving up the beach and may require avoiding obstacles in shallow water.
- This EDR supports littoral and open ocean Naval operations.

Weapon Systems Support

- Specific attribute values of this EDR are needed for global and regional ocean forecast model input to yield values needed for littoral sediment transport and turbidity analyses for special warfare and mine warfare operations.
- Resolution and accuracy requirements are needed to bound detection and accuracy parameters for emerging shallow water ASW.
- Knowledge of currents locations helps raise the probability of detection of submarines and saves sonobuoy resources (1990 NOARL study).
- This EDR supports ship to shore resupply actions.

General Forecasting

- This EDR is used to test and evaluate ocean circulation models.
- Forecasters user ocean current models, which used satellite measurements as inputs, to predict the onsets of devastating natural events such as El Nino.

Ice/Ocean Analysis

- The NOAA Center for Ocean Analysis Prediction (COAP) uses ocean current information to support development of a unique series of environmental and living marine resource analyses, forecasts and assessments that describe and predict the condition and variability of biological, chemical and physical oceanic phenomena, as well as the processes affecting them.
- Currents (along with surface winds) provide a valuable aid for forecasting yields of certain marine species dependent upon transport for spawning.

Climate/Atmospheric Monitoring

- Ocean currents are major factors in meridonal heat transport and exchange. Fluctuations in their intensity are keys to the monitoring of climate change and the associated affect on living marine resources. Ocean currents also move a significant amount of energy from the tropics towards the poles leading to a moderation of the climate at high latitudes. Understanding ocean circulation is essential to understanding global climate.

Note1: The foremost limiting factor for detailed analysis of current structures, especially at high latitudes is horizontal resolution.

Note2: Littoral current details (i.e., eddies) can be taken into proper consideration only by a high resolution model using a polar-orbiting weather satellite.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Radar Altimeter (C & Ku Band)

EDR: Freshwater Ice Edge Motion

Definition: This parameter is the ice property derived from imagery EDRs.

Uses: Climate/Atmospheric Monitoring

- Snow and ice are significant because their formation and disappearance involve large transfers of latent heat. They have major effects on turbulent heat transfer from underlying land or water to the atmosphere.

General Forecasting

- It is necessary to distinguish ice from clouds for satellite interpretations in order to improve cloud analyses and cloud/no-cloud decisions in support of mission planning.

Safety of Operations

- Ice floe forecasts made by the National Ice Center affect the safety of vessels in the Great Lakes during winter.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

EDR: Ice Surface Temperature

Definition: This parameter measures ice surface temperature and a 2 meter ambient air temperature (two distinct measurements).

Uses:

Ice/Ocean Analysis

- Ice surface temperature and a temperature two meters above the ice surface (objective) are used to determine the thickness (age) of ice.

Navigation/Trafficability

- This parameter is important for ships transitting through the ice.

General Forecasting

- This EDR is used in ice growth models for operational ice forecasting.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

EDR: Littoral Sediment Transport

Definition: This parameter measures the transport of sediment by river systems and along shore currents (in m^3/day).

Measurement: Measurements of littoral sediment transport are severely impacted by low solar illumination angle because of the low refractivity of water.

Uses:

Weapon Systems Support

- This EDR is used to analyze optical clarity including rates of sediment deposition in littoral areas to bound detection and accuracy parameters for emerging mine warfare systems and for mine detection operations.

Safety of Operations

- It is used for mission planning for global amphibious operations; must make sure divers can see.
- This EDR is used to predict surf conditions (affected by ocean bottom characteristics) which affects on-shore troop landings
- Littoral sediment affects sound speed profile. Knowledge of actual sound speed profiles (versus using an random guess) to place sonobuoys supports optimization of placement of these ASW resources.

Oceans & Ice

- This EDR is monitored as part of the CoastWatch program.

Note: Littoral sediment transport forecasting depends heavily on the skill of predicting coastal ocean currents.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Net Heat Flux

Definition: This parameter measures the difference between incoming and outgoing radiation at the air/sea interface.

Uses:

<u>General Forecasting</u>

- This EDR is essential to the correct physical modeling of natural phenomena occurring at the air/sea interface for both numerical meteorological and oceanographic prediction models.
- Specific EDR attribute levels are needed for input into global models to yield prognostic charts used to forecast mesoscale features in support of naval operations worldwide.

<u>Climate/Atmospheric Monitoring</u>

- This EDR is a parameter in climate models.

Instrumentation:

Imager/Radiometer (VIS/IR/LL)
Sounder (IR X-track)
Temperature Sounder (MW X-track)
Imager/Sounder (MW Conical)

EDR: Ocean Color/Chlorophyll

Definition: This EDR measures the color of the ocean as seen from a distance of at least one meter or the chlorophyll content of water.

Measurement: Measurements of ocean color are baselined for the 1330 NPOESS orbit because high solar illumination is required to monitor the low reflectivity of the ocean surface.

Uses: Ice/Ocean Analysis

- The NOAA Status and Trends Program for Marine Environmental Quality provides an assessment on a national scale of the environmental quality conditions around the U.S. coasts and of the changes that are occurring in these conditions. Remotely sensed ocean color data is needed to estimate the plant pigment concentrations to provide an assessment of nutrient overenrichment conditions and associated problems (e.g., algal blooms). A remotely sensed estimate of chlorophyll is the only practical means for following large-scale spatial and temporal fluctuations in nutrient overenrichment conditions. Ocean color data supports near shore pollution assessments.
- Ocean color data is needed to detect water mass differences to deduce the location of ocean currents and water mass mixing over the continental shelf.
- This EDR is an indicator of coastal erosion/sediment transport.
- Ocean color and thermal boundaries are used by tuna fisherman in the Pacific Ocean to locate favorable fishing areas. Ocean color imagery is also used to describe oceanic processes related to specific types of fish spawning and distribution and ocean/biological productivity
- Ocean color data will be used to generate real-time oceanographic products such as littoral eddy and current identification, sediment plume identification, water clarity and underwater visibility estimates, chlorophyll a concentration (and associated bioluminescence potential), potential acoustic ambient noise and backscatter characteristics from projected biomass concentration.
- The oil industry in interested in this EDR for assessing impacts on deep water drilling.
- The need for specific HSR is due to the smaller spatial scales of regional features as compared to the open ocean.
- Adequate mapping accuracy and range is essential to geolocation and measurement of coastal and estuarine features (e.g., phytoplankton patches) for resource managers.

- Both HSR and mapping accuracy support resolving ocean temperature structures.

Climate/Atmospheric Monitoring
- This EDR provides estimates/indices of CO_2 sinks in the coastal marine areas relevant to climate change.

Weapon Systems Support
- Chlorophyll concentration of 0.5-50g/m^3 is required to calculate the extinction of solar radiation with depth as a function of chlorophyll concentration. [This information supports ASW operations and prediction of E-O system performance.]
- As is helps support identification of ocean fronts and eddies, this EDR is used to optimize use of ASW sonobuoys.

General Forecasting
- This EDR is used in global ocean circulation models.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

EDR: Ocean Wave Characteristics

Definition: This EDR measures the height and period/frequency of ocean waves.

Uses:

General Forecasting

- This information validates wave model performance (with wind speed data) in areas where there are no data buoys.

Weapon Systems Support

- Sea state affects missile/weapons launches.

Safety of Operations

- Sea state affects flight operations (carrier aircraft may need to be ditched if sea state worse than predicted).
- Personnel and mission safety (due to dangerous wave condition) benefit greatly from knowledge of this information.
- Sea state affects site selection/operations at port and beach facilities, over-water logistics, shore landing, special operations and tactical operations near coastal areas.
- This EDR is used to estimate turbulence in local and coastal areas.

C^4I Systems Support

- Sea state affects radar clutter.

General Forecasting

- This EDR is used to produce wave analysis fields for initialization and generation of ocean wave forecasts.
- Remotely sensed observations are incorporated into the restart field of NOAA's ocean wave (NOW) model that supports warning and forecast activities.

Instrumentation: Radar Altimeter (C & Ku Band)

EDR: Sea Ice Age and Sea Ice Edge Motion

Definition: This parameter measures ice properties which are derived from imagery EDRs.

Uses:

Ice/Ocean Analysis

- This EDR is used to produce tactical ice scale analyses/ice forecasts showing ice edge position, ice concentration, thickness, age, and direction of drift. JIC provides specialized ice services such as the identification and analysis of leads and multi-year ice for units operating outside the icepack. This EDR is also used to identify the presence of icebergs and/or ice islands.

Climate/Atmospheric Monitoring

- Changes in sea ice in polar regions would be an early indicator of possible global temperature change.
- Snow and ice are significant because their formation and disappearance involve large transfers of latent heat. They have major effects on turbulent heat transfer from underlying land or water to the atmosphere.

Safety of Operations

- This EDR is important for guidance of ships through ice-infested waters. Sudden wind changes can cause compacting of ice which can damage ships if they are not aware of the changing ice condition.
- Ice edge information is important to Alaskan fishermen and for resupply operations on the North Slope.
- Ice concentrations, ice age and ice hardness are provided to Coast Guard ice breakers, research vessels, Arctic ice camps, and military resupply ships going to the DEW line and Greenland.
- This EDR supports shipping and submarine activities in the Arctic and Antarctic.
- This EDR must be high resolution and all weather to ensure safety of navigation.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
Imager/Sounder (MW Conical)

EDR: Sea Surface Height/Topography

Definition: Sea surface height is the longwave horizontal variations in the height of the sea surface with respect to the geoid.

Uses:

Ice/Ocean Analysis

- Measurements of the dynamic height of the ocean surface are useful because "height gradients" can be related to the speed of large scale current systems of the world.
- Height can be used to detect oceanographically significant features, such as the location of the "north wall" of the Gulf Stream and the location and movement of the warm and cold eddies associated with this important current system.
- Remotely sensed measurements of dynamic height will be used by NOS to improve the accuracy of existing ocean features analyses and in expanding the current modeling program.
- This EDR is useful to off-shore drilling, coastal protection industries, marine research and determining lake levels.
- This EDR supports the measurement of the mean level of oceans which is of particular interest to low-lying countries.

General Forecasting

- NOAA models that benefit from this data include ocean/numerical circulation models that supports NOAA in carrying out its mandated responsibilities in oil and hazardous substance spill response, water quality studies, search and rescue and environmental management.
- The resolution and accuracy requirements cited for this EDR are needed for emerging coupled ocean-atmosphere models.
- This EDR is used to identify anomalies such as El Nino.

Safety of Operations

- This information is useful for ocean-bound shipping.
- This EDR is used in surf/conditions forecasts for on-shore troop landings

Climate/Atmospheric Monitoring

- SSH/T is used to understand estimates of upper-layer heat content that are used to forecast ocean/atmosphere events as much as 6 months in advance.
- This EDR is needed for the correct representation of air-sea fluxes.

<u>Weapon Systems Support</u>

- Assessment of ocean current features to support military missions requires this EDR. SSH/T from a polar orbiting satellite provides the only means of acquiring the high quality global data needed to analyze transient ocean current features (i.e., eddies, fronts) to the resolution and accuracy requirements needed for emerging mine warfare and ASW systems. Ocean fronts and eddies are acoustically complex and represent areas in which submarines and surface ships can "hide" to minimize the probability of being detected through acoustic means.
- As is helps support identification of ocean fronts and eddies to support current identification, this EDR is used to optimize use of ASW sonobuoys.

Instrumentation: Radar Altimeter (C & Ku Band)

EDR: Surface Wind Stress

Definition: This EDR measures the frictional stress of the wind acting on the sea surface, causing it to move as a wind-drift current, and causing the formation of waves.

Uses:

General Forecasts

- The measurement of surface wind stress is very valuable in providing estimates of ocean surface wind to drive ocean wave forecast models and in the maintenance of ocean currents. US Navy verification studies of the Spectral Ocean Wave Model (SOWM) reveal that such models will not yield results any better than the wind fields that drive the model.
- The finer the resolution or cell size, the closer one can come to the littoral region for special studies of upwelling and other near-shore ocean events and the less data are lost.
- This EDR is used to determine the effects of winds on sea conditions for military operations.

Climate/Atmospheric Monitoring

- This EDR is used in climate models of the interaction between ocean and atmosphere.

Instrumentation: Imager/Sounder (MW Conical)

EDR: Turbidity

Definition: This parameter measures the suspended matter in the ocean. Turbidity may be derived from ocean color data.

Measurement: Measurement of turbidity is severely impacted by low solar illumination angle.

Uses:

Weapon Systems Support

- This information is used to analyze optical clarity including rates of sediment deposition in littoral areas to bound detection and accuracy parameters for emerging mine warfare systems. Without this data, the Navy would be forced to use climatological data. A sensing depth of 50m is needed to analyze the majority of enclosed ocean basins and coastal areas where mine and special warfare operations will occur.

Safety of Operations

- It is necessary for Navy Seals to assess if they will be able to see underwater (e.g., if Navy Seals are called to conduct placement of charges on underwater structures as part of an overall attack plan, the mission could be jeopardized due to the inability to see)

Ice/Ocean Analysis

- Turbidity measurements would be used to map/quantify estuarine discharge and coastal currents and are required to assess marine environmental quality as well as ecosystem health for biological production. Turbidity has impact on light reaching the bottom thus limiting sea grass growth and fish larval survival for stock replenishment. The geolocation of estuarine and coastal marine features such as river discharges/plumes and storm induced bottom suspended sediment have much more stringent location requirements than in open ocean and therefore require a better mapping accuracy.
- Turbidity is indicative of run-off

Navigation/Trafficability

- Turbidity measurements support coastal navigation.

Instrumentation: Imager/Radiometer (VIS/IR/LL)

Space Environment Parameters

The space environmental parameters must be measured continuously in each orbital plane as specified resolutions, to get a representative sampling of the ionosphere, which is itself semi-sun-synchronous. In addition, equal spacing, and adequate coverage of the dawn/dusk transitions and the approximate noon/midnight fluctuations are necessary. One exception is solar EUV flux which is obtained by viewing the sun directly.

EDR: Auroral Boundary

Definition: This EDR shows the location of the boundary of the auroral zone.

Uses: C^4I Systems Support

- Changes and gradients in ionospheric electron densities and magnetic field impact radar, and ground communications and navigation systems. Especially for radar looking north, the problem is the occurrence of auroral interference and clutter. This clutter can scatter and/or attenuate HF, VHF, and UHF radar energy and can cause large doppler shifted returns, and/or produce false targets or give false launch indicators. Spacetrack radar may experience unusual signal retardation and refraction, causing ranging and pointing errors. SATCOM may have problems with enhanced phase and amplitude scintillation. This also affects GPS since phase fluctuations stress the receiver's ability to acquire and process the signal resulting in a loss of tracking capabilities and degradation of information contained within the signal.
- Changes in upper atmospheric density due to the variability in the auroral zone energy deposition affect satellite drag and therefore satellite orbit prediction.

Hazard Identification/Warnings

- Knowledge of the auroral boundary location gives NASA shuttle and civilian high altitude aircraft information on location of regions of enhanced radiation so they can avoid over exposure to astronauts and aircraft personnel.

Climate/Atmospheric Monitoring

- This EDR supports determination of global Neutral Density Profiles.

Note: Coverage must be less than 60^{o} so that the most disturbed periods will be observed when they are needed most.

Instrumentation: Imager/Radiometer (VIS/IR/LL)
FUV/EUV (ABIS Limb)
Vector Mag (AVM)
GPS Receiver (GPSR)
Spectrometer (MEPS)

EDR: Total Auroral Energy Deposition

Definition: This EDR is the physical heat input parameter required for models of atmospheric densities.

Uses: Climate/Atmospheric Monitoring

- Optical remote sensing is used to map the intensity and location of auroral energy deposition in the upper atmosphere, as well as to detect shock waves in the interplanetary solar winds, which cause geomagnetic disturbances on Earth. These observations are important to future enhancements of the solar terrestrial services carried out by NOAA OAR.

Weapon Systems Support

- Auroral emissions and airglow are required to delineate targets from thermospheric and ionospheric backgrounds at infrared, visible and vacuum ultraviolet wavelengths.

Instrumentation: Spectrometer (MEPS)

EDR: Auroral Imagery

Definition: Auroral imagery is specialized imagery in the proper wavelengths to allow visual interpretation of auroral characteristics.

Uses:

General Forecasting

- Auroral imagery is used to define the auroral boundary and to derive various auroral geophysical parameters, including auroral energy deposition rates.

Hazard Identification/Warnings

- Auroral imagery supports warnings to pilots and shuttle crews of enhanced radiation.

Weapon Systems Support

- Auroral imagery is one of the optical backgrounds against which weapons system must operate.

Instrumentation:

Imager/Radiometer (VIS/IR/LL)
FUV/EUV (ABIS Limb)
FUV/EUV (NADIS)

EDR: Electric Field

Definition: This EDR shows a vector field at a location in the immediate external environment of the satellite wherein any charged particle would experience an electrical force.

Measurement: The 0530 NPOESS terminator orbit is the preferred orbit for this measurement in the DMSP system.

Uses:

Climate/Atmospheric Monitoring

- Estimates of atmospheric expansion and resulting satellite drag depend on observations of the energy being deposited in the upper atmosphere at high latitudes. These observations include the precipitating charged auroral particles and the electric and magnetic fields with which they interact to produce Joule heating as well as the geographic extents of the Polar caps regions and of the flux and spectrum of the solar protons which have free access to these regions.

General Forecasting

- Electric field data in the auroral and polar cap regions are needed as input to operational space environmental models of the magnetosphere and ionosphere.
- This measurement partially fulfills requirements for global ionospheric specification needed to determine the amount of auroral heating, which in turn is an input required by Neutral Atmospheric Models.

Instrumentation: Drift Meter (RPA-D)

EDR: Electron Density Profiles/Ionospheric Specification

Definition: This EDR specifies the ionosphere by measuring electron density profiles, total electron content, and identifying characteristics of the layer of maximum electron density (F2) by height in meters (HmF2), electron density (NmF2) and critical frequency (foF2).

Uses:

C^4I Systems Support

- Specification and forecast of ionospheric parameters are necessary to minimize impacts on a variety of ground and space-based surveillance and communications systems. These affects include significant azimuth, elevation, range, and cross-section measurement errors on long range radar systems which accomplish the missile warning/space surveillance mission (PAVE PAWS, BMEWS etc.), degradation of target detection performance and unacceptable range errors on backscatter radar systems (OTH-B, ROTHR), and significant degradation of tactical and long range high frequency communications.
- This EDR is used to analyze and forecast the ionosphere for frequency management of long-haul high-frequency communication and long-range radars (OTH-B), for ionospheric refraction and retardation of space track radars, and for forecasting potential satellite communications and navigation system problems. Ionospheric disturbances affect frequency utilization and jamming capability.

General Forecasting

- Direct & derived parameters include maximum electron densities at corresponding altitudes in the D, E & F regions of the ionosphere, measurements of topside scale heights and complete vertical profiles and total electron contents along arbitrary electromagnetic ray paths through the ionosphere and plasmasphere. These measurements provide key parameters for models, forecasting, ray tracing, and other types of corrective applications in support of DOD, DOC and National Program systems.

Instrumentation:

FUV/EUV (ABIS Limb)
GPS Receiver (GPSR)
Drift Meter (RPA-D)
Ion Meter (BEACON)
FUV/EUV (NADIS)

EDR: Geomagnetic Field

Definition: This EDR provides measurements of the Earth's vector magnetic field at spacecraft location.

Uses:

Climate/Atmospheric Monitoring

- Estimates of atmospheric expansion and resulting satellite drag depend on observations of the energy being deposited in the upper atmosphere at high latitudes. These observations include the precipitating charged auroral particles and the electric and magnetic fields with which they interact to produce Joule heating as well as the geographic extents of the Polar cap regions and of the flux and spectrum of the solar protons which have free access to these regions.
- This EDR supports assessment of Neutral Atmospheric Specification.
- Measurements of the Earth's vector magnetic field are required to infer the strength of ionospheric and magnetospheric current systems used to determine the atmospheric heat input in the auroral zone.

C^4I Systems Support

- This EDR is required to discern impacts to over-the-horizon radars pointed across or near the Auroral zone.

General Forecasting

- This EDR is required to specify the variability of the earth's magnetic field and to detect geomagnetic disturbances. This EDR provides routine observations and forecasts for the earth's geomagnetic field.

Hazard Identification/Warnings

- It supports alert notification of geomagnetic storms, exercises and contingencies, and planetary geomagnetic indices.
- This EDR provides event notifications and warnings.

Instrumentation: Vector Mag (AVM)

EDR: In-Situ Ion Drift Velocity

Definition: This EDR provides measurements of in-situ plasma drift velocities.

Measurement: The 0530 terminator orbit is the preferred orbit for this measurement in the current DMSP system.

Uses:

General Forecasting

- This EDR is used to infer electric field strengths and patterns in the auroral and polar cap regions.
- This EDR is used to determine the location of the high latitude trough region in support of a global ionospheric specification requirement (used by ionosphere models).

C^4I Systems Support

- Changes in high-latitude ionospheric convection pattern impact high-latitude radars, degrade HR and transionospheric satellite communications and enhance drag for low-altitude polar orbiting satellites.
- This EDR can be used in predicting whether scintillation will occur for a particular communication system.

Instrumentation: Drift Meter (RPA-D)

EDR: In-Situ Plasma Density

Definition: This EDR provides ion composition information required to determine the altitude of transition between oxygen and lighter ion species.

Uses:

General Forecasting

- Ion composition information is required to estimate the altitude of transition between oxygen and lighter ion species, which is an input to high altitude ionospheric models.

C^4I Systems Support

- Changes in high-latitude ionospheric convection pattern impact high-latitude radars, degrade HR and transionospheric satellite communications and enhance drag for low-altitude polar orbiting satellites.

Instrumentation: GPS Receiver (GPSR)
Drift Meter (RPA-D)

EDR: In-Situ Plasma Fluctuations

Definition: This EDR provides measurement of ionospheric structures responsible for scintillation occurring primarily at altitudes near the peak of the F2 region (250-400km).

Uses:

General Forecasting

- This EDR partially satisfies the requirements for measurements of ionospheric scintillation. CkL measurements are determined from in-situ observations and are required to drive the operational models of the 50 WS.

C^4I Systems Support

- Changes in high-latitude ionospheric convection pattern impact high-latitude radars, degrade HR and transionospheric satellite communications and enhance drag for low-altitude polar orbiting satellites.
- This EDR is used to assess and forecast scintillation induced outages to global communication and navigation systems.

Instrumentation: Drift Meter (RPA-D)

EDR: In-Situ Plasma Temperature

Definition: This EDR measures plasma temperatures measured in the mid-latitude region.

Uses: General Forecasting

- This EDR supports the requirement for Global Ionospheric Specification.
- This EDR supports determination of ionospheric scale heights via mid-latitude temperatures.

C^4I Systems Support

- Changes in high-latitude ionospheric convection pattern impact high-latitude radars, degrade HR and transionospheric satellite communications and enhance drag for low-altitude polar orbiting satellites.
- This EDR supports investigation of spacecraft anomalies.

Instrumentation: Drift Meter (RPA-D)

EDR: Ionospheric Scintillation

Definition: This EDR measures the fluctuation of both amplitude and phase of an electromagnetic frequency signal caused by variations in electron density along the line of sight.

Measurement: Scintillation phenomena typically occur within two hours of the solar terminator (in the post sunset sector) and the 0530 orbit is a minimum required orbit for this measurement.

Uses:

C^{4}I Systems Support

- Temporal and spatial fluctuations in the ionospheric electron density lead to disruptions of transionospheric communications links and GPS navigation signals and can affect spacetrack radar. SATCOM may have problems with enhanced phase and amplitude scintillation. This also affects GPS since phase fluctuations stress the receiver's ability to acquire and process the signal resulting in a loss of tracking capabilities and degradation of information contained within the signal.
- This EDR is used to assess and forecast scintillation induced outages to global communication and navigation systems.
- This EDR is required to analyze environmental conditions which distort satellite communication and spacetrack radars.

General Forecasting

- Three parameters are used operationally to characterize ionospheric properties from which scintillation effects may be estimated. The most critical is CkL (height integrated strength parameters irregularity spectral index) which is derived/inferred from other measurements and is used to drive operational models at 50 WS.
- This EDR provides corrections for ionospheric refraction, event notifications and warnings, routine observations, and forecasts for the earth's ionosphere. It is used to support exercises and contingencies by providing corrections for ionospheric refraction.

Instrumentation: GPS Receiver (GPSR)
Drift Meter (RPA-D)
Ion Meter (BEACON)

EDR: Neutral Density Profiles/Neutral Atmospheric Specification

Definition: This EDR is a measurement of upper atmospheric densities.

Uses: C^4I Systems Support

- Spacecraft and debris orbiting below a few hundred km altitude encounter significant atmospheric densities throughout their orbit. Changes in the atmosphere density can significantly alter the orbit and, if unexpected and severe enough, the object can be "lost" by tracking radar or ground sites. In the case of satellite systems, this impacts the ground site's ability to acquire the satellite for command and control purposes, and in the case of AFSPC tracking radar, this impacts the accuracy of the space order of battle. Without global coverage, efficiency of tracking satellites would be degraded and transatmosphere flight profiles may be adversely affected.
- This EDR is used for prediction and specification of satellite drag for orbit and re-entry predictions, prediction of satellite ephemeris, and radiative transfer.

General Forecasting

- Accurate measurements of upper atmospheric densities and scale heights are required to provide inputs for the development and validation of, and possible ingest by these operational specification and forecast models.
- Atmospheric models are the primary means for accurately accounting these changes in atmospheric density (see above) and allowing calculations of expected drag and its affect on low orbiting objects.

Instrumentation: FUV/EUV (ABIS Limb)
FUV/EUV (NADIS)

EDR: Radiation Belt and Low Energy Solar Particles

Definition: This EDR provides measurements of particles through this energy range.

Uses:

General Forecasting

- This EDR supports determination of the boundary and extent of the polar cap.
- This EDR provide inputs to various space environment technology models.

C^4I Systems Support

- This information is required to assist in the analysis of satellite anomalies, involving surface charging and, at higher energies, deep dielectric charging and radiation damage.
- This information is required for pitch angles both within the atmospheric loss cone and near local mirroring to determine that portion of the particle population entering the atmosphere.

Instrumentation: Particle Spectrometer (HEPS)
Spectrometer (MEPS)

EDR: Solar and Galactic Cosmic Ray Particles

Definition: This parameter provides measurements of particles through this energy range.

Uses:

Hazard Identification/Warnings

- This EDR is used to analyze radiation hazards to satellites, astronauts and aircraft personnel. Measurement range must be sufficient otherwise large uncertainties will be introduced leading to inability to completely assess radiation effects.

General Forecasting

- This EDR provides routine observations and forecasts for the sun.
- This EDR helps determine the boundary and extent of the polar cap and provide inputs to models.

Hazard Identification/Warnings

- This EDR supports event notifications and warnings, alert notification of solar flares and exercises and contingencies by providing solar forecasts.

C^4I Systems Support

- This EDR assists in the analysis of satellite anomalies, semiconductor and solar cell radiation damage.
- This EDR is required for pitch angles both within the atmospheric loss cone and near local mirroring to discriminate that portion of the particle population entering the atmosphere for that which is trapped.
- Galactic Cosmic Rays (GCRs) can cause satellite microcircuitry logic upsets, sensor contamination and false signals in orientation sensors.
- This EDR is needed to specify Polar Can Absorption (PCA); PCA can black out HR radio systems in high latitude regions.

Instrumentation: Particle Spectrometer (HEPS)

EDR: Solar EUV Flux

Definition: This EDR provides a measurement of that portion of the solar spectrum which is responsible for creation of the Earth's ionosphere as well as much of the heating of the upper atmosphere.

Uses: General Forecasting

- This EDR provides partial satisfaction of requirements of ionospheric and neutral atmospheric specification.
- This EDR supports determination of the ionospheric state. This EDR will provide a more accurate measurement of the ionospheric state. It enhances all mission areas affected by the ionosphere.
- This EDR is an input to various space environment technology models.

Note: Solar EUV information is totally absorbed in the upper atmosphere and must be measured from space.

Instrumentation: FUV/EUV (ABIS Limb)
FUV/EUV (NADIS)

EDR: Supra-Thermal through Auroral Energy Particles

Definition: This EDR provides measurements of particles through this energy range.

Uses: General Forecasting

- This EDR supports determination of the boundary and extent of auroral regions and provide inputs to the various models.

C^4I Systems Support

- This EDR assists in the analysis of satellite anomalies, particularly surface chargings.
- This EDR is required to determine pitch angels both within the atmospheric loss cone and near local mirroring to determine that portion of the particle population entering the atmosphere.

Instrumentation: Spectrometer (MEPS)

EDR: Upper Atmospheric Airglow

Definition: This EDR provides measurements of airglow in the extreme and far ultraviolet portions of the spectrum used to infer the density of upper atmospheric neutral and ionized constituents. This EDR provides measurements of the magnitude (intensity) of particular frequencies of particle emissions. Units of R (Rayleighs) and kR (kiloRayleighs) are units of photon brightness.

Measurement: The 0530 orbit is a minimum required source of data for both airglow and scintillation data.

Uses:

Climate/Atmospheric Monitoring

- In the post-sunset sector, equatorial airglow imagery can provide signatures of ionospheric disturbances associated with scintillation.
- This EDR is used to infer the density of upper atmospheric neutral and ionized constituents.

General Forecasting

- This EDR partially fulfills requirements for global ionospheric and neutral atmospheric specification.

Weapon Systems Support

- This EDR is a natural background against which some weapon systems operate.

Instrumentation: FUV/EUV (ABIS Limb)
FUV/EUV (NADIS)

Unaccommodated Parameters

EDR: Tropospheric Winds

Definition: This EDR measures wind throughout the troposphere.

Uses:

Climate/Atmospheric Monitoring

- Accurate and timely knowledge of the direction and speed of global tropospheric winds would significantly improve the understanding and prediction of weather and climate. Currently, tropospheric wind data is derived from indirect measurements from satellite-retrieved temperature measurements. Benefits from improved prediction of climate due to accurate global wind data include economic benefit from either unwarranted action or inaction in response to the uncertain prospect of global climate change, improved hurricane forecasts and general forecasting abilities and better fuel consumption planning by commercial airlines.
- A wind profile is required for cloud returns and planetary boundary layer aerosol returns.

Safety of Operations

- This information supports aviation flight planning.

Hazard Identification/Warnings

- This EDR supports the prediction of dispersal of atmospheric pollutants.

Instrumentation: Wind Lidar

EDR: Ozone Profile - High Resolution

Definition: This EDR measures ozone concentration within a specified volume

Uses: (see information on page 14)

Climate/Atmospheric Monitoring

- Ozone controls the amount of biologically damaging UV radiation reaching the surface and it must be measured with sufficient accuracy to allow for the detection of decadal rates of change.

Instrumentation: Limb Scanner (Ozone Profiler)

EDR: Methane (CH_4) Column

Definition: This EDR is a measure of the amount of methane contained in a specified volume of air.

Uses:

Climate/Atmospheric Monitoring

- The presence of trace gases in the atmosphere can have a significant effect on global change. The chemical composition of the troposphere in particular is changing at a unprecedented rate. The rate at which pollutants from human activities are input to the troposphere is now thought to exceed that from natural sources (e.g., volcanic eruptions) and is known to be greater than the atmosphere's natural capacity for their removal.
- This EDR allows monitoring changes in the composition of the various layers in the atmosphere and to deduce the effects of these changes on the global climate. High spectral resolution is needed to detect the absorption, emission or scattering for individual species (trace gases)
- This EDR is used to understand sources and sinks of trace gases. In atmospheric chemistry, there is strong evidence of increasing concentrations of cfcs, carbon dioxide, methane etc. Realistic scenarios for future atmospheric concentrations, especially for methane, are difficult to deduce because of an inadequate understanding of the sources and sinks of these substances. Major uncertainties in the future evolution of the ozone layer arise from the uncertain future concentrations of atmospheric methane and from inadequate knowledge of the distribution of several stratospheric constituents, such as water vapor.
- This EDR supports the monitoring of greenhouse gases and an understanding of the role of humans on these concentrations.

Hazard Identification/Warnings

- The presence of trace gases in the atmosphere can have a significant effect on potentially harmful local effects through increased levels of pollution.

Instrumentation: Spectrometer (MOPITT)

EDR: Carbon Monoxide (CO) Column

Definition: This EDR is a measure of the carbon monoxide contained in a specified volume of air.

Uses:

Climate/Atmospheric Monitoring

- The presence of trace gases in the atmosphere can have a significant effect on global change. The chemical composition of the troposphere in particular is changing at a unprecedented rate. The rate at which pollutants from human activities are input to the troposphere is now thought to exceed that from natural sources (e.g., volcanic eruptions) and is known to be greater than the atmosphere's natural capacity for their removal.
- This EDR supports monitoring of changes in the composition of the various layers in the atmosphere and to deduce the effects of these changes on the global climate. High spectral resolution is needed to detect the absorption, emission or scattering for individual species (trace gases).

Hazard Identification/Warnings

- The presence of trace gases in the atmosphere can have a significant effect on potentially harmful local effects through increased levels of pollution.

Instrumentation: Spectrometer (MOPITT)

EDR: Carbon Dioxide (CO_2) Column

Definition: This EDR is a measure of the carbon dioxide contained in a specified volume of air.

Uses:

Climate/Atmospheric Monitoring

- This EDR supports monitoring of sources and sinks of CO_2. CO_2 is a chemically stable gas that has an important effect on climate. The present ground-based network is probably adequate for monitoring its steady increase, which is in part because of the burning of fossil fuels, and secondarily to deforestation. For studying sources and sinks, however, it is necessary to monitor the geographical and seasonal variations which would require a spaceborne monitoring system.
- The presence of trace gases in the atmosphere can have a significant effect on global change. The chemical composition of the troposphere in particular is changing at a unprecedented rate. The rate at which pollutants from human activities are input to the troposphere is now thought to exceed that from natural sources (e.g., volcanic eruptions) and is known to be greater than the atmosphere's natural capacity for their removal.
- This EDR is used to monitor changes in the composition of the various layers in the atmosphere and to deduce the effects of these changes on the global climate. High spectral resolution is needed to detect the absorption, emission or scattering for individual species (trace gases).

Hazard Identification/Warnings

- The presence of trace gases in the atmosphere can have a significant effect on potentially harmful local effects through increased levels of pollution.

Instrumentation: Spectrometer (TBD)

EDR: Optical Backgrounds

Definition: This EDR measures emissions that are the result of interactions between precipitating energetic particles and solar ultraviolet radiation with neutral atmospheric constituents.

Uses: Weapon Systems Support

- Optical Background data is used to set thresholds for threat detection systems supporting missile and space defense assets.

Instrumentation: TBD

EDR: Bathymetry

Definition: This EDR measures the vertical depth of water.

Measurement: Performance of this EDR can be severely impacted at low solar illumination angle.

Uses:

Ice/Ocean Analysis

- This EDR is used to produce tactical scale ice analyses showing ice edge position, ice concentration, thickness, age, and direction of drift.

Navigation/Trafficability

- This EDR must be high resolution and all-weather to ensure safety of navigation.
- This EDR is used to locate and identify the presence of icebergs and/or ice islands.
- This EDR is used in support of a variety of USN missions due to it as input information for acoustics.

General Forecasting

- Collection, processing, and distribution of precise bathymetric data supports bathymetric profiles and databases.

Instrumentation: TBD

EDR: Bioluminescence

Definition: This parameter is a measurement of the number of bioluminescent organisms present in sea water within a region.

Uses:

Ice/Ocean Analysis

- This EDR is used to determine gravity, magnetic field, ocean fronts, sea state, surf, tides, and water clarity.

Safety of Operations

- The Navy will use this EDR to assess the vulnerability to detection of Navy/Joint assets. Submarines are forced to operate in more shallow coastal waters and special warfare operations conducted along coastlines are extremely vulnerable to detection when bioluminescence occurs. Bioluminescence potential is usually greater in coastal areas, which are highly variable (temporally and spatially). Bioluminescence signatures are useful in search and rescue operations. Four Navy requirements address the need for bioluminescence data to better understand and use the environment to meet mission objectives. Without the remote sensing capability, the Navy will continue to use existing database holdings and shipboard collection capability in very limited areas.

Hazard Identification/Warnings

- Reduced light output by bioluminescent organisms after exposure to toxic substances can help identify potential threat/environmental problems.

Instrumentation: TBD

EDR: Salinity

Definition: This EDR is a measure of the quantity of dissolved materials in sea water. A formal definition of this EDR is “the total amount of solid materials, in grams, contained in one kilogram of sea water, when all carbonate has been converted to oxide, the bromine and iodine converted to chlorine, and all organic matter is completely oxidized. Units of measurement are parts per thousand, by weight”

Uses:

<u>Hazard Identification/Warnings</u>

- This EDR is used for dumpsite monitoring (NOS)

<u>General Forecasting</u>

- Information about salinity can provide useful information on the physical properties of the ocean for use in modeling activities. Remotely sensed salinity would provide the data to support two major functions: 1) near real-time input to <u>ocean dynamic models</u> as initial sounding conditions and as a continually refreshed data source for assimilation; 2) feed databases on a global scale, instead of the presently used ships of opportunity.
- Salinity from remotely sensed platforms would provide the capability to define one more initial variable; otherwise it is status quo, and salinity will be based on climatological data.

<u>Weapon Systems Support</u>

- Salinity data is used to support mine warfare, mine countermeasure warfare, amphibious warfare and special warfare missions. Five Navy requirements address need for salinity/sound velocity data.

<u>Ice/Ocean Analysis</u>

- This EDR is used to produce tactical scale ice analyses showing ice edge position, ice concentration, thickness, age, and direction of drift.
- This EDR is used to determine ocean fronts and water clarity.
- Salinity observations contribute to oceanic and lake studies.

<u>Safety of Operations</u>

- This EDR must be high resolution and all-weather to ensure safety of navigation. It is used to locate and identify the presence of icebergs and/or ice islands.

Instrumentation: TBD

		Service/Agency	Doc Number	Document Title	Document Date	POC:
	1	Army	fax	IORD RCM II Citations	Apr-95	LTC Clayton
	2	CJCS	CJCSI 3810.01	Meteorological and Oceanographic Operations	10-Jan-95	
	3	Army		Engineer Update to Army Wartime Weather Support Requirements; Requirement for Improved Weather Information	Nov-94	Dep. C of S, for Intel; USA Eng. School
	4	Army	FM 34-81/ AFJPAM 15-127	Weather Support for Army Operations		
	5					
**	6	USAF/AWS		Use of Polar-orbiting Meteorological Satellite Data by Air Force Weather [RCM II Inputs - IORD 0)	Apr-95	LTC Harcourt
**	7	USAF		DMSP Block Six, EDR Requirements Comparison and Sensor Capability (briefing)		
xx	8	USAF		Reference Letters for Inputs to RCM II/IORD 0*		
xx	9	USAF		List of AF User Community @ 27 July 95		
	10	USAF/AWS		Concept Paper for Weather Support to AF Theater Operations (1995 - 2005)	5-May-92	
	11	HQ USAF/XORD	AFDD 45	Aerospace Weather Operations	31-Aug-94	
	12	HQ AFFSA/XOFD	AFI 11-206	Flying Operations, General Flight Rules		
	13	HQ AWS/DOO	AFM 15-111 V2	Surface Aviation Observations Meteorological Aviation Support	31-May-94	
**	14					
	15	USN		RCM II Reference Listing		
	16	USN	AD-B113 775	How Many Silver Bullets to Shoot?	15-May-87	CDR Pearson
	17	USN/Navair		Tactical Aircraft Mission Planning System Environmental Data Requirements		
	18	FNMOC		EDR Matrix Comments		LCDR Don Conlee
	19	USN/Chief of NavOps		Meteorolgy and Oceanography General Reqt's	24-Jul-95	
	20	USN/Naval Weapons Center	TN 4073-74	A Survey of Environmental Effects on the Performance of Conventional Weapons Systems	Nov-75	
	21	SEL(NOAA)/50WS		Space Environmental Monitoring Requirements for Polar Orbiting	Jul-95	Capt. Cade
	22	AWS/XORR		Inputs based on RFI (AVMP, TP and Imagery)	Oct-95	Capt. Zuccarello
	23	Aerospace		Review of Cloud EDRs	4-Aug-95	Jim Pranke
	24	SMC/CIIR		Review of DMSP Follow-On ORD	8-Jul-93	Capt. Lee
**	25	NOAA		Inputs based on RFI	27-Oct-95	Mr. Lawrence
	26	Aerospace		A Weather Forecast Utility Model for Military Missions		Mr. Bohlson

		Service/Agency	Doc Number	Document Title	Document Date	POC:
	27	Aerospace		Funtional Description AFGWC/SYSM	17-May-93	Capt. Waldron
	28	USAF/AFSPC		Environmental Sensing MNS	13-Aug-92	
	29	Naval Western Oceanography Center		Environmental Critical Values for Military Operations	9-Oct-87	
	30	Navy		Various critical values/impacts for Naval Ops		
	31	Johns Hopkins U		Measurement Resolution Criteria for Assessment of Coastal Ducting	Apr-95	Goldhirsh & Dockery
	32	JHU		AEGIS Environmental Data Requirements	14-Jul-94	
	33	Navy		Various sheets: Research Initiatives vs. Fleet Requirements		
	34	COMNAVMETOC COM		A guide to USMC Concepts for Force Employment, Deployment and Development		Major Bill Resavy
**	35	USAF - XPX		MNS: Environmental Monitoring; Space-Based Environmental Monitoring		
	36	Army	FM 34-81-1	Battlefield Weather Effects	23-Dec-92	
	37	GWU/NWS/NOAA		Economic Benefits and Costs of Developing and Deploying a Space -Based Lidar	Mar-95	Cordes & Flanagan
	38	NRL NOAA U Maryland		Climate Study Suite Report on Ozone Sensors for NPOESS	31-Aug-95	Lucke, Planet, Hudson
xx	39	NOAA		RCM II NOAA Citation Inputs		
	40	NOAA - DOD - NASA		Tri-Agency Polar Requirements Summary (note: in NOAA folder)	Oct-93	
	41	NOAA		NOAA Requirements fo Support From Polar-Orbiting Satellites	Jun-90	
	42	AFSC - MAC		WX 2000 Executive Summary	1984	
**	43	SMC		NPOESS Requirements Issues (letter)	1995	Maj. Belsma
	44	JCS		METOC Operations	1995	
**	45	AWS		Use of Polar-orbiting Meteorological Satellite Data by Air Force Weather [RCM II Inputs - IORD 0)		
	46	GAO	TL 798 E7 U675+ 1986	User Views on the Consequences of Eliminating a Civilian Polar Orbiter	Mar-86	
**	47	SPACECOM		Transmittal of NPOESS IORD RCM II inputs	Jul-95	
	48	Users		Responses to Rationale Worksheets	Sep-95	
	49	US DOC, NOAA, NESDIS	NOAA Tech Report, NESDIS 16	Temporal and Spatial Analysis of Civil Marine Satellite Requirements	Feb-86	N. J. Hooper, J.W. Sherman III

		Service/Agency	Doc Number	Document Title	Document Date	POC:
	50	US DOC, NOAA, NESDIS	NOAA Tech Report, NESDIS 41	Report of the Earth Radiation Budget Requirements Review - 1987; Rosslyn, Virginia 30 March - 3 April 1987	Jun-88	Edited by L. L. Stowe; Sat. Research Lab. Atmos. Sciences Branch
	51	US DOC		National Environment Satellite, Data and Information Service		DOC
	52	NOAA	vol AES 20, Number 4	NOAA Satellite Programs (reprinted from IEEE Transactions on Aerospace and Electronic Systems)	Jul-84	E. S. Epstein, W. M. Callicott, D. J. Cotter, H.W. Yates (NOAA)
	53	NOAA/NASA		Space-Based Remote Sensing of the Earth , A Report to Congress	Sep-87	NOAA, NASA
	54	NOAA?	1995 COES Yearbook	The Committee on Earth Observing Satellites - Coordination for the Next Decade		
	55	DOC/NOAA		Strategic Plan, A Vision for 2005 (Executive Summary)	Mar-95	R. H. Brown (DOC); D. J. Baker (NOAA)
	56	USN	SER-AIR-5260W/042	Information for the DMSP COEA	Mar-93	LCDR Z.S. Willis
	57	General Research Corp.		COBRA Benefits Briefing	Jan-96	W. Hutchison
	58	General Research Corp		COBRA Homepage (hardcopy)	Feb-96	W. Hutchison
**		reference only				
xx		not applicable to database				

APPENDIX F

LIFE CYCLE COST ANALYSIS DETAILS

[Appendix F has been deleted from this report since it contains Government Cost Information which may no longer be representative of the current NPOESS program.]

Appendix G

Operational Benefit Impact Assessments

Organization of Data

- **Data is presented only for those EDRs that are different between the COBRA alternatives**
- **Data is presented by COBRA alternative, describing only risks and limitations of the alternative due to lack of EDRs**
- **Data is presented by Functional Category**
  - **Forecasts and Warnings (F&W)**
  - **Oceans and Ice (O&I)**
  - **Solar and Space Environment (S&SE)**
  - **Climate (C)**
  - **Military Unique Applications (MUA)**
- **Data is presented by agency (DOC, DoD)**
- **All information shown is based on information from Appendix E of COBRA report (organized by EDR with table of references)**

EDR to Functional Category Mapping

	COBRA EDR Differences	F&W	O&I	S&SE**	C	MUA
Ocean/Water	Currents (near shore/surface)		X		X	X
	Littoral Sediment Transport		X			X
	Ocean Color/Chlorophyll		X		X	X
	Turbidity		X			X
	Ocean Wave Characteristics		X			X
	Sea Surface Height/Topography		X			X
ERB	Downward Longwave Radiation (surface)				X	
	Insolation				X	
	Total Longwave Radiation (TOA)				X	
	Net Shortwave Radiation (TOA)				X	
	Solar Irradiance				X	
P^3I*	Tropospheric Winds	X				X
	Ozone Profile - High Resolution				X	
	CH_4 (Methane) Column				X	
	CO (Carbon Monoxide) Column				X	
	CO_2 (Carbon Dioxide) Column				X	

* Optical backgrounds, bathymetry, bioluminescence and salinity were not considered by the COBRA

** Not addressed by COBRA since all EDRs impacting this area are satisfied

Color Assessments

- Color ratings were used to summarize the ability to accomplish relevant missions within each functional area
- A functional area received an overall assessment of “Red” if impact to one or more missions was critical (severe limitations and risks or complete mission failure)
- A functional area received an overall assessment of “Yellow” if impact to one or more missions was not critical but there still exist some limitations and risks
- A functional area received an overall assessment of “Green” if all relevant missions were able to be accomplished without limitations and risks
  - Note that “Green” assessments are not discussed further

Preliminary Results by Functional Area

	ALT 1	ALT 2 (IORD-I)	ALT 3A (P^3I)	ALT 3B (P^3I)
Forecasts and Warnings (F&W)	Y	Y	G	Y
Oceans and Ice (O&I)	Y	G	G	G
Solar and Space Environment (S&SE)	G	G	G	G
Climate (C)	Y	Y+	Y+	G
Military Unique Applications (MUA)	R	Y	G	Y

Red = Critical Mission Impact; Yellow = Risks & Limitations to Mission Accomp.; Green = Mission Accomplishment

Results Overview

- <u>Forecasts & Warnings</u> changes from "Yellow" to "Green" based on addition of the tropospheric winds EDR
- <u>Oceans & Ice</u> changes from "Yellow" to "Green" based on addition of ocean/water EDRs
- <u>Solar & Space Environment</u> is satisfied to IORD-I thresholds for all alternatives
- <u>Climate</u> changes from "Yellow" to "Yellow+" based on the addition of earth radiation budget (ERB) EDRs, and changes from "Yellow+" to "Green" based on the addition of trace gases and enhanced ozone EDRs
- <u>Military Unique Applications</u>* changes from "Red" to "Yellow" based on addition of "system survivability" and ocean/water EDRs and changes from "Yellow" to "Green" based on the addition of the tropospheric winds EDR.

*** All impacts to DoD were considered under this category**

Overall Issues

- **Common to DOC and DoD**
  - **Global coverage, especially over open ocean where polar satellites are the only source of data**
  - **Improvements in forecasting ability are limited without growth in capabilities (better data)**
- **DOC only**
  - **Reliance on enhancement of capabilities and the ability to explore unique opportunities to gather data from unexpected sources to support NOAA's R&D mission**
  - **Maintenance of high quality, continuous data collection to support long-term environmental policy recommendations**

Overall Issues (concluded)

0 **DoD only**

- **Exploitation of environmental phenomena (e.g., ocean parameters) for tactical and defensive mission planning**
- **Ability to react appropriately (minimize damage) to quick-changing environmental conditions in tactical situations**
- **Maintenance of long-term climate databases to support strategic and logistic planning**

EDRs Satisfied by All Alternatives (50)

Vertical Moisture Profile*	Cloud Optical Depth/ Transmittance	Normalized Difference Vegetation Index
Vertical Temperature Profile*	Cloud Top Height	Ozone Total Column/Profile
Imagery*	Cloud Top Pressure	Precipitable Water
Sea Surface Temperature*	Cloud Top Temperature	Precipitation (Type/Rate)
Sea Surface Winds*	Electric Field	Pressure (Surface/Profile)
Soil Moisture*	Electron Density Profiles/ Ionospheric Specification	Radiation Belt and Low Energy Solar Particles
Aerosol Optical Thickness	Freshwater Ice Edge Motion	Sea Ice Age and Sea Ice Edge Motion
Aerosol Particle Size	Geomagnetic Field	Snow Cover/Depth
Albedo (Surface)	Ice Surface Temperature	Solar and Galactic Cosmic Ray Particles
Auroral Boundary	In-situ Ion Drift Velocity	Solar Extreme Ultra Violet Flux
Total Auroral Energy Deposition	In-situ Plasma Density	Supra-thermal through Auroral Energy Particles
Auroral Imagery	In-situ Plasma Fluctuations	Surface Wind Stress
Cloud Base Height	In-situ Plasma Temperature	Suspended Matter
Cloud Cover/Layers	Ionospheric Scintillation	Total Water Content
Cloud Effective Particle Size	Land Surface Temperature	Upper Atmospheric Airglow
Cloud Ice Water Path	Net Heat Flux	Vegetation Index/SurfaceType
Cloud Liquid Water	Neutral Density Profiles/Neutral Atmospheric Specification	

Alternative 1 Results

Alternative 1 - DOC Results

- Forecasts and Warnings - Yellow
  - Lack of tropospheric wind EDR
- Oceans and Ice - Yellow
  - Lack of ocean/water EDRs
- Climate - Yellow
  - Lack of ERB, enhanced ozone, trace gases

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions: Forecasting: Aviation, Maritime, Hurricane	**Importance:** Winds are fundamental to all weather phenomena; 500 mb winds steer weather and drive climate

Risks & Limitations

• limited accuracy of forecast models using derived measurements (currently)
• limited hurricane warnings and forecasts of storm track
(improvements could reduce direct damage, loss of life and limb and over-warning; simulations have shown that having accurate global wind measurements on the scale of hurricanes can improve forecasting accuracy by 17%*)
• non-optimized fuel load/consumption for commercial airlines and ships
(with improvements, expect reduction in fuel consumption of 0.5% domestic, 1.0% international*)
• limited hazard warnings
• limited knowledge (with respect to coverage/timeliness) of important characteristics of El-Nino could minimize ability to avert excess damage from storms

* *Economic Benefits and Costs of Developing and Deploying a Space-Based Wind Lidar*, J. J. Cordes, Ph.D. (D-9502)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Currents	Sparse measurements via commercial shipping; drifting and fixed buoys; research instruments on satellites; flyovers
Missions:	**Importance:**
Marine/Fisheries Mgt. and Support	Developing & disseminating a unique series of living marine resource analyses and forecasts (e.g., fish abundance, availability and behavior)

Risks & Limitations

- limited understanding of the long-term economic and biological sustainability of U. S. fishing resources due to:
  - limited ability to forecast yields of shrimp and other species dependent upon transport during spawning
  - limited ability to determine the transport of fish larvae by wind induced currents (currents moving offshore during peak spawning periods adversely impacts the fishery by reducing the number of larvae entering estuaries)
- sparse data, no continuous archives

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Currents	Sparse measurements via commercial shipping; drifting and fixed buoys; research instruments on satellites; flyovers
Mission:	**Importance (concluded):**
Navigation	In combination with other observations (e.g., water levels), provides better open ocean information for commercial shipping

Risks & Limitations

- non-optimal route planning (in terms of safety (e.g., ice hazards) and fuel load/consumption)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDRs Lacking:	**Current Capability:**
Turbidity and Littoral Sediment Tr.	Limited information from airplane reconnaissance and imagery of known “murky”/polluted areas
Missions:	**Importance:**
Coastal Navigation; Marine Env. Quality (s&d assess)	Understand and track movement of sandbars; determine marine environmental quality and ecosystem health for biological production

Risks & Limitations

• trafficability problems in known areas, worse for areas that are not well known (i.e., sparsely populated areas with limited infrastructure); lesser known areas will have limited uses for commercial navigation (must rely on standard reference materials with no granularity)

• no information on local, short-term anomalies

• limited ability to make effective long-term environmental (ecosystem health) policy recommendations; unable to determine impacts to sea grass growth and fish larval survival for stock replenishment (light sensitive) nor detect harmful growths (e.g., algal blooms)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking: Ocean Color/ Chlorophyll	**Current Capability:** Data from research instruments on satellites (there will be a gap until ADEOS); data from ships
Missions: Marine Env. Quality; Fisheries; Coastal Mgt.	**Importance:** Estimate the plant pigment concentrations in order to assess nutrient overenrichment conditions and associated problems; locate favorable fishing areas (e.g., tuna); assess chlorophyll concentration within surface water; develop near-shore pollution assessments

Risks & Limitations

- spotty data, no long-term archiving which hinders NOAA's R&D mission
- unable to effectively recommend long-term environmental policies
- limited understanding of the long-term economic and biological sustainability of U. S. fishing resources
- regional accuracy only (comparison between ship and satellite chlorophyll data were within 20% - satellites "buy" global accuracy)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ocean Wave Characteristics	Fixed and drifting buoys; ship observations
Mission:	**Importance:**
Maritime Forecasts	Generate wave forecasts from NOAA's ocean wave (NOW) model; small craft advisories; storm surges

Risks & Limitations

- limited to local/regional coverage, which may result in excess damage to both land and sea assets
- limited performance of wave models
- limited data on global coastal turbulence resulting in unnecessary small craft advisories

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
SSH/Topo	Ship-launched bathythermographs; non-real time data from current satellite systems
Mission:	**Importance:**
Maritime Forecasts	Support off-shore exploration for resources and for pipeline routing on the sea bed; contributes to knowledge of El-Nino changes

Risks & Limitations

- limited knowledge (with respect to coverage/timeliness) of important characteristics of El-Nino could minimize ability to avert excess damage from storms
- inefficient off-shore exploration and pipeline routing

Alternative: 1

F&W	**O&I**	S&SE	C	MUA
Y	**Y**	G	Y	R

EDR Lacking: SSH/Topo	**Current Capability:** Ship-launched bathythermographs; non-real time data from current satellite systems
Mission: Climate Monitoring/ Env. Quality	**Importance (concluded):** Refine geoid over oceans; measure dynamic height of ocean surface (height gradients can be related to large scale current systems of the world); detect oceanographically significant features

Risks & Limitations

- limited knowledge (with respect to coverage/timeliness) of important characteristics of the Gulf Stream (e.g., "north wall") may cause damage to ships operating around this area

- less improvement in the accuracy of ocean features analysis and numerical circulation models limits NOAA's effectiveness in oil/hazardous spill response, water quality studies, search and rescue, and environmental management

- limited ability to determine current locations in sparsely populated areas and wave heights prior to storm which could avert significant personnel/property harm

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ocean Color/ Chlorophyll	Aircraft flyovers; visual data; ships with buoys to provide in-situ measurements
Mission:	**Importance:**
Global Change Monitoring	Allows an assessment of ocean productivity which is a fundamental component of the global carbon cycle (high latitude oceans are potential carbon sinks)

Risks & Limitations

- not able to fully understand biological cycles nor ascertain global warming trends without this component
    - phytoplankton converts dissolved carbon dioxide into other compounds, absorbing CO_2 into the atmosphere released by fossil fuels
- spotty data, no long-term archiving which limits NOAA's R&D mission
- unable to effectively recommend long-term environmental policies

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Currents	Sparse measurements via commercial shipping; drifting and fixed buoys; research instruments on satellites
Mission:	**Importance:**
Global Climate Monitoring	Ocean circulation plays an important role in the Earth's climate system; ocean currents move a significant amount of energy (away from the equator) leading to moderation of the climate at high latitudes

Risks & Limitations

• because of sparse data, very limited knowledge exists of the three dimensional state and circulation of the world's oceans and their variations

• limited ability to gain estimates of upper-layer heat content thereby limiting prediction of ocean/atmosphere events via Numerical Prediction models

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDRs Lacking:	Current Capability:
Radiation; insolation	Limited to occasional research instruments on satellites
Mission:	**Importance:**
Climate Monitoring	Determines the net energy flux for the earth that is necessary to understand the processes by which the atmosphere, land, and oceans transfer energy to achieve global radiative equilibrium which in turn is necessary to simulate and predict climate*

Risks & Limitations

- can only initialize various models (med. range forecast, radiation fields) with estimates of insolation, leading to reduced prediction capability
- spotty information; no continuous global measurements for climatic trend analysis; conflicting products from models (needed for model validation)
- unable to effectively recommend long-term environmental policies

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Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Solar Irradiance	Limited data from ground-based sensors; research instruments on satellites
Mission:	**Importance:**
Climate Monitoring	Used to monitor the total and spectral solar irradiance for determining solar influence on global change; solar variability can influence global surface temperatures and middle atmosphere ozone concentrations

Risks & Limitations

• inability to assess total UV radiation; data from ground-based sensors provides radiation data after it passes through the atmosphere

• no long-term, continuous records of the variable energy input for reliable analyses and predictions of future solar forcing of global change

• limited understanding of the solar cycle

• inability to effectively differentiate between human-induced environmental impacts and solar trends

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ozone Profile - High Resolution	Variable (7-15 km vertical resolution) from SBUV-2 on POES
Mission:	**Importance:**
Climate Monitoring	Ozone controls the amount of biologically damaging UV radiation reaching the surface

Risks & Limitations

- insufficient vertical resolution to allow for detection of decadal rates of change

- major ozone changes are now occurring in the 18-22 km altitude range; ozone depletion due to anthropogenic effects is difficult to measure today; for tropospheric ozone, there is major uncertainty in the natural variation; accurate measurement of stratosphere trends, with high vertical resolution in the lower stratosphere is needed to detect tropospheric trends; once these trends are established, then the causes for ozone depletion, other than natural, can be determined, and policies to deal with human-induced causes can be prescribed

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
CO_2	Ground-based sensor network to monitor increases in CO_2
Mission:	**Importance:**
Climate Monitoring	Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- current sensors cannot isolate sources and sinks of CO_2, which are necessary to monitor geographic and seasonal changes
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

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F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

Alternative: 1

EDRs Lacking:	Current Capability:
CO & CH_4	Measured from occasional research instruments on satellites
Mission:	**Importance:**
Climate Monitoring	Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- spotty measurements lead to inability to get long-term, continuous, global data needed to determine trends in the chemical composition of the troposphere
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

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Alternative 1 - DoD Results

- **Military Unique Applications - Red***
  - **Lack of “system survivability”**
  - **Lack of ocean/water EDRs**

*** Lack of tropospheric wind EDR does not contribute to the “Red” assessment**

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

Capab. Lacking:	Current Capability:
"System Survivability"	Limited; DMSP 5D3 only
Missions:	**Importance:**
All	Use of data in all mission/operational situations for DoD and NOAA

Risks & Limitations

- In the event of an intentional or unintentional occurrence of one of the "threats" described in Section 1.2 of COBRA report, some or all of the NPOESS performance capability could be degraded or lost completely.

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions:	**Importance:**
In/exfiltration; NBC Ops; Air Drops Artillery Fires; Concealment; Flight Ops	All aspects of mission planning/execution; calculations of fuel consumption, estimated time over target, landing & recovery actions; predicting nuclear, biological and chemical (NBC) contamination; forecasts supporting weapons delivery & employment; storm tracking

Risks & Limitations

• non-optimized routing and fuel load/consumption, causing inefficient mission planning (possibly critical)
• non-optimized use of advanced weapon systems
• limited knowledge (with respect to coverage/timeliness) of storms could minimize ability to avert excess damage from storms
• inaccurate wind data may cause paratroopers to be off-target and exposed to hostile activity and injury

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking: Currents	**Current Capability:** Current velocity only from ships (e.g., Coast Guard); dropped buoys; Navy Seals; flyovers
Mission: Carrier Battle Group (CBG); Amphibious Ops	**Importance:** Near-shore (littoral) and open ocean operations

Risks & Limitations

• since Navy operations are global, sparse and regional information on currents results in surprises (as was found in Indian Ocean) that can be extremely detrimental to world-wide operations safety

• for CBG refueling, the carrier, due to its size, will pass through a current prior to the smaller ship refueling; lack of knowledge regarding changes in currents, specifically velocity, could force the carrier into the other ship with casualties and major asset damage if the current is stronger than anticipated; without global, accurate information, this scenario is likely, esp. in more remote parts of the world

• global mission planning for amphibious operations must consider timing and height of tides; infiltration at low tide results in more exposure while moving up the beach and may require avoiding obstacles in shallow water

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking: Currents	**Current Capability:** Current velocity only from ships (e.g., Coast Guard); dropped buoys; Navy Seals; flyovers
Mission: Naval Operations	**Importance (concluded):** Used to produce tactical scale ice analyses (e.g., direction of drift); locate/identify icebergs/ice islands in the polar regions; test and evaluation of ocean circulation models; used to exploit ocean phenomena in support of U. S. forces

Risks & Limitations

- accurate global water levels and current predictions are needed for safe and efficient world-wide navigation and to prevent vessel accidents especially in areas where icebergs exist

- limited ability to initialize ocean circulation models leading to a limited predictive capability especially in the long-term

- limited ability to exploit ocean phenomena and to defend against hostile exploitation of phenomena (e.g., submarines can hide under currents)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDRs Lacking:	Current Capability:
Turbidity and Littoral Sediment Tr.	Limited information from airplane reconnaissance and imagery of known “murky”/polluted areas
Missions:	**Importance:**
Mine Warfare; Amphib. Warfare	Used to analyze optical clarity including rates of sediment deposition in littoral areas to bound detection and accuracy parameters for emerging mine warfare systems

Risks & Limitations

- limited ability to detect mines

- mission planning for global amphibious ops; if Navy Seals are going to be deployed they will not be able to determine the state of the water (i.e., will the frogmen be able to see?)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ocean Color/ Chlorophyll	Aircraft flyovers; visual data; ships with buoys to provide in-situ measurements
Mission:	**Importance:**
Mine Warfare; Amphib. Ops	Generate real-time oceanographic products; eddy and current identification; estimates of underwater visibility, water depth and bioluminescence

Risks & Limitations

- limited use of water-mass differentiation as a global operational tool due to limited coverage and fidelity
- reduced mission planning for littoral coastal operations
- limited ability to exploit ocean phenomena and to determine obstacles for amphibious operations

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking: Ocean Wave Characteristics	**Current Capability:** Use models to generate OWC from wind data from microwave imager; data buoys; ship observations
Mission: Carrier Battle Group (CBG); Deep & Shallow Water Ops	**Importance:** This EDR is used to determine sea state and significant wave height (SWH) and to validate wave model performance (with wind speed data) in areas where there are no data buoys

Risks & Limitations

• safety of operations; if SWH is not provided worldwide, model performance must be extrapolated from areas where in-situ measurements are available (e.g., data buoys) increasing the risk of actions taken based on bad forecasts for critical operations in denied areas; flight operations especially may be at risk if sea state is greater than predicted since new landing sights may need to be found or aircraft need to be ditched; there is risk to the carrier itself and impacts can be fatal to personnel and extreme to military assets

• limited ability to initialize models leading to limited predictive capabilities

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ocean Wave Characteristics	Use models to generate OWC from wind data from microwave imager; data buoys; ship observations
Mission:	**Importance (continued):**
Carrier Battle Group (CBG)	This EDR is used to determine sea state and significant wave height (SWH)

Risks & Limitations

• defensive capability limited due to inability to discern sea-skimming missiles from ocean clutter

• ship radar capability is reduced as SWH increases, therefore, if you don't understand the sea state you will not understand radar limitations and will not be able to change your operations strategy to be in the best defensive or offensive position

• reduced mission planning over the horizon (OTH); lack of prior knowledge of sea state could cause non-optimization of asset deployment (a P-3 aircraft may be less vulnerable than a submarine in specific sea state conditions)

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
Ocean Wave Characteristics	Use models to generate OWC from wind data from microwave imager; data buoys; ship observations
Mission:	**Importance (continued):**
Submarine Ops/ Weapons Plan.	This EDR is used to determine sea state and significant wave height (SWH)

Risks & Limitations

- inaccurate forecasts of sea state may limit the effectiveness of various sub-launched weapons due to required low-altitude flights; major inaccuracies can make costly launches completely ineffective

- sea state determines the maximum depth at which the missiles can be launched and it affects radar clutter and can limit the use of missiles with low-altitude flight

- sea state affects weapon engagement planning, system launch and employment decisions

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking: Ocean Wave Characteristics	**Current Capability:** Use models to generate OWC from wind data from microwave imager; data buoys; ship observations
Mission: Logistics; Amphibious Ops	**Importance (concluded):** This EDR is used to determine sea state, tides and significant wave height (SWH)

Risks & Limitations

• it is critical to accurately and globally predict sea state for these ops, otherwise personnel and cargo are put at risk if decisions are made with sparse data

• unable to determine optimum transportation routes; unable to open re-supply port facilities during contingencies; logistics ops are significantly affected by seas > 1meter; most maritime shipping is impacted when seas reach 4 meters; impact is serious when seas are 7 meters, as speed must be significantly reduced and safety of ship and cargo are placed at risk

• global mission planning for amphibious operations must consider timing and height of tides; infiltration at low tide results in more exposure while moving up the beach and may require avoiding obstacles in shallow water

Alternative: 1

F&W	O&I	S&SE	C	MUA
Y	Y	G	Y	R

EDR Lacking:	Current Capability:
SSH/Topo	Non-real time data from ERS-1 and TOPEX (short-life R&D satellite); ship-launched bathythermographs
Mission:	**Importance:**
Sub Operations	Locates fronts and eddies; provides ambient noise characteristics and acoustics info; provides tactical ice scale analyses; initializes ocean circulation models

Risks & Limitations

- no real-time data link and no polar coverage; raw data not available using current sources

- limited ability to exploit ocean phenomena; difficult to determine cold and warm core eddies that are acoustically complex and represent areas in which submarines and surface ships can "hide" to minimize the probability of being detected by acoustic means; inability to hide from hostile platforms or detect hostile platforms within these areas would be fatal to USN vessels

- limited predictive capability due to lack of raw, global data

Alternative 2 Results

Alternative 2 - DOC Results

- Forecasts and Warnings - Yellow
  - Lack of tropospheric wind data
- Oceans and Ice - Green
  - Addition of ocean/water EDRs
- Climate - Yellow+
  - Lack of enhanced ozone, trace gases

Alternative: 2

F&W	O&I	S&SE	C	MUA
Y	G	G	Y+	Y

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions: Forecasting: Aviation, Maritime, Hurricane	**Importance:** Winds are fundamental to all weather phenomena; 500 mb winds steer weather and drive climate

Risks & Limitations

• limited accuracy of forecast models using derived measurements (currently)
• limited hurricane warnings and forecasts of storm track
(improvements could reduce direct damage, loss of life and limb and over-warning; simulations have shown that having accurate global wind measurements on the scale of hurricanes can improve forecasting accuracy by 17%*)
• non-optimized fuel load/consumption for commercial airlines and ships
(with improvements, expect a reduction in fuel consumption of 0.5% domestic, 1.0% international*)
• limited hazard warnings
• limited knowledge (with respect to coverage/timeliness) of important characteristics of El-Nino could minimize ability to avert excess damage from storms

* ***Economic Benefits and Costs of Developing and Deploying a Space-Based Wind Lidar*,**
J. J. Cordes, Ph.D. (D-9502)

Alternative: 2

F&W	O&I	S&SE	C	MUA
Y	G	G	Y+	Y

EDR Lacking: **Ozone Profile - High Resolution**	**Current Capability:** **Variable (7-15 km vertical resolution) from SBUV-2 on POES**
Mission: **Climate Monitoring**	**Importance:** **Ozone controls the amount of biologically damaging UV radiation reaching the surface**

Risks & Limitations

- **insufficient vertical resolution to allow for detection of decadal rates of change**

- **major ozone changes are now occurring in the 18-22 km altitude range; ozone depletion due to anthropogenic effects is difficult to measure today; for tropospheric ozone, there is major uncertainty in the natural variation; accurate measurement of stratosphere trends, with high vertical resolution in the lower stratosphere is needed to detect tropospheric trends; once these trends are established, then the causes for ozone depletion, other than natural, can be determined, and policies to deal with human-induced causes can be prescribed**

Alternative: 2

F&W	O&I	S&SE	C	MUA
Y	G	G	Y+	Y

EDR Lacking:	Current Capability:
CO_2	Ground-based sensor network to monitor increases in CO_2
Mission:	**Importance:**
Climate Monitoring	Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- current sensors cannot isolate sources and sinks of CO_2, which are necessary to monitor geographic and seasonal changes
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

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Alternative: 2

F&W	O&I	S&SE	C	MUA
Y	G	G	Y+	Y

EDRs Lacking:	Current Capability:
CO & CH_4	Measured from occasional research instruments on satellites
Mission:	**Importance:**
Climate Monitoring	Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- spotty measurements lead to inability to get long-term, continuous, global data to determine trends in the chemical composition of the troposphere
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

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Alternative 2 - DoD Results

0 **Military Unique Applications - Yellow**

- **Lack of tropospheric wind data**

Alternative: 2

F&W	O&I	S&SE	C	MUA
Y	G	G	Y+	Y

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions: In/exfiltration; NBC Ops; Air Drop; Artillery Fires; Concealment; Flight Ops	**Importance:** All aspects of mission planning/execution; calculations of fuel consumption, estimated time over target, landing & recovery actions; predicting NBC contamination; forecasts supporting weapons delivery & employment; storm tracking

Risks & Limitations

- non-optimized routing and fuel load/consumption, causing inefficient mission planning (possibly critical)
- non-optimized use of advanced weapon systems
- limited knowledge (with respect to coverage/timeliness) of storms could minimize ability to avert excess damage from storms
- inaccurate wind data may cause paratroopers to be off-target and exposed to hostile activity and injury

Alternative 3A Results

Alternative 3A - DOC Results

- Forecasts & Warnings - Green
  - Addition of tropospheric wind EDR
- Oceans & Ice - Green
  - Addition of ocean/water EDRs
- Climate - Yellow+
  - Lack of enhanced ozone, trace gases

Alternative: 3A

F&W	O&I	S&SE	C	MUA
G	G	G	Y+	G

EDR Lacking:	**Current Capability:**
Ozone Profile - High Resolution	Variable (7-15 km vertical resolution) from SBUV-2 on POES
Mission:	**Importance:**
Climate Monitoring	Ozone controls the amount of biologically damaging UV radiation reaching the surface

Risks & Limitations

- insufficient vertical resolution to allow for detection of decadal rates of change

- major ozone changes are now occurring in the 18-22 km altitude range; ozone depletion due to anthropogenic effects is difficult to measure today; for tropospheric ozone, there is major uncertainty in the natural variation; accurate measurement of stratosphere trends, with high vertical resolution in the lower stratosphere is needed to detect tropospheric trends; once these trends are established, then the causes for ozone depletion, other than natural, can be determined, and policies to deal with human-induced causes can be prescribed

Alternative: 3A

F&W	O&I	S&SE	C	MUA
G	G	G	Y+	G

EDR Lacking:	Current Capability:
CO_2	Ground-based sensor network to monitor increases in CO_2
Mission:	**Importance:**
Climate Monitoring	Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- current sensors cannot isolate sources and sinks of CO_2, which are necessary to monitor geographic and seasonal changes
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

** 1995 CEOS Yearbook*

Alternative: 3A

F&W	O&I	S&SE	C	MUA
G	G	G	Y+	G

EDRs Lacking: CO & CH_4	**Current Capability:** Measured from occasional research instruments on satellites
Mission: Climate Monitoring	**Importance:** Measurement of trace gases is vital both to monitor changes in the composition of various layers in the atmosphere and to deduce the effects of these changes on the global climate*

Risks & Limitations

- spotty measurements lead to inability to get long-term, continuous, global data to determine trends in the chemical composition of the troposphere
- limited ability to understand potentially harmful local effects through increased levels of pollution (role of humans)
- unable to effectively recommend long-term environmental policies

** 1995 CEOS Yearbook*

Alternative 3A - DoD Results

- **Military Unique Applications - Green**
  - **Addition of tropospheric wind EDR**

Alternative 3B Results

Alternative 3B - DOC Results

- Forecasts and Warnings - Yellow
  - Lack of tropospheric wind EDR
- Oceans and Ice - Green
  - Addition of ocean/water EDRs
- Climate - Green
  - Addition of enhanced ozone, trace gases

Alternative: 3B

F&W	O&I	S&SE	C	MUA
Y	G	G	G	Y

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions: Forecasting: Aviation, Maritime, Hurricane	**Importance:** Winds are fundamental to all weather phenomena; 500 mb winds steer weather and drive climate

Risks & Limitations

• limited accuracy of forecast models using derived measurements (currently)
• limited hurricane warnings and forecasts of storm track
(improvements could reduce direct damage, loss of life and limb and over-warning; simulations have shown that having accurate global wind measurements on the scale of hurricanes, can improve forecasting accuracy by 17%*)
• non-optimized fuel load/consumption for commercial airlines and ships
(with improvements, expect a reduction in fuel consumption of 0.5% domestic, 1.0% international*)
• limited hazard warnings
• limited knowledge (with respect to coverage/timeliness) of important characteristics of El-Nino could minimize ability to avert excess damage from storms

* *Economic Benefits and Costs of Developing and Deploying a Space-Based Wind Lidar*, J. J. Cordes, Ph.D. (D-9502)

Alternative 3B - DoD Results

0 **Military Unique Applications - Yellow**
  - **Lack of tropospheric wind EDR**

Alternative: 3B

F&W	O&I	S&SE	C	MUA
Y	G	G	G	Y

EDR Lacking:	Current Capability:
Trop. Winds	Derived by analysis/indirectly from measurements of temperature/pressure profiles; limited (not to IORD-I levels)
Missions: In/exfiltration NBC Ops, Flight Ops, Artillery Fires, Concealment Air Drops	**Importance:** All aspects of mission planning/execution; calculations of fuel consumption, estimated time over target, landing & recovery actions; predicting NBC contamination; forecasts supporting weapons delivery & employment; storm tracking

Risks & Limitations

• non-optimized routing and fuel load/consumption, causing inefficient mission planning (possibly critical)
• non-optimized use of advanced weapon systems
• limited knowledge (with respect to coverage/timeliness) of storms could minimize ability to avert excess damage from storms
• inaccurate wind data may cause paratroopers to be off-target and exposed to hostile activity and injury

Back-Up Information (Mapping of the IORD 14 Functional Areas)

- **Forecasts & Warnings**
  - **Aviation forecasts, medium range forecast outlook, tropical cyclone warnings, severe storm and flood warnings**
- **Oceans & Ice**
  - **Forecasts of ice features, hydrologic forecasts, forecasts of ocean surface and internal structures**
- **Solar and Space Environmental Forecasts**
- **Climate**
  - **Seasonal and interannual climate forecasts, decadal-scale monitoring of climate variability, assessment of long-term global environmental change, environmental air quality monitoring and emergency response**
- **Military Unique Applications**
  - **Tactical decision aids, weapon systems utilization**

APPENDIX H

ACRONYMS

A

ABIS	Auroral Boundary and Ionization Sensor
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADO	Associate Director for Operations
AFB	Air Force Base
AFGWC	Air Force Global Weather Central
AFI	Air Force Instruction
AFMC	Air Force Material Command
AFMC/SMC	Air Force Material Command/Space and Missile Center
AFSFC	Air Force Space Forecast Center
AFSC	Air Force Systems Command
AFSCN	Air Force Satellite Control Network
AFSPC	Air Force Space Command
AIRS	Advanced (Atmospheric) Infrared Sounder
ALT	Alternative
AMSU	Advanced Microwave Sounding Unit
APT	Automatic Picture Transmission
ARGOS	French Data Collection System
ARTS	Automated Remote Tracking Station
ASW	Antisubmarine Warfare
AVM	Advanced Vector Magnetometer
ATN	Advanced TIROS-N
AVHRR	Advanced Very High Resolution Radiometer
AVMP	Atmospheric Vertical Moisture Profile
AVTP	Atmospheric Vertical Temperature Profile

B

B	Billion
BEACON	(Navy situational awareness program)
BMEWS	Ballistic Missile Early Warning System

C

C	Climate
CARD	Cost Analysis Requirements Document
CBG	Carrier Battle Group
C^3	Command, Control, and Communications
CDA	Command and Data Acquisition
CEOS	Committee on Earth Observing Satellites
CER	Cost Estimating Relationship
CERES	Clouds and Earth’s Radiant Energy System
CH_4	Methane
CM	Chairman’s Memo (DoD Joint Chiefs of Staff); Cost Model; Configuration Management

CMISS	Conical Microwave Imager/Sounder Suite
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COAP	Center for Ocean Analysis and Prediction
COBRA	Cost, Operational Benefit, and Requirements Analysis
COEA	Cost and Operational Effectiveness Analysis
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf

D

DCA	Defense Contract Agency
DCS	Data Collection System
DDT&E	Design, Development, Test and Evaluation
DEW	Defense Early Warning
DJSM	Director Joint Staff Memo
DLR	Downward Longwave Radiation
DMA	Defense Mapping Agency
DMSP	Defense Meteorological Satellite Program
DNA	Defense Nuclear Agency
DOC	Department of Commerce
DoD	Department of Defense
DOMSAT	Domestic Satellite
DRR	Data Routing and Retrieval
DST	Decision Support Tool

E

EDR	Environmental Data Record
EELV	Extended Expendable Launch Vehicle
EIA	Earth Incidence Angle
E-M	Electro-Magnetic
EMD	Engineering and Manufacturing Development
ENSO	El-Nino Southern Oscillation
E-O	Electro-Optical
EOS	Earth Observing System
EOTDA	Electro-Optical Tactical Decision Aid
ERB	Earth Radiation Budget
ERS	Earth Resources Satellite
ESA	European Space Agency
ESSA	Environmental Satellite Service Administration
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EUV	Extreme Ultra Violet

F

F&W	Forecasts and Warnings
FNMOC	Fleet Numerical Meteorological Oceanography Center
FOC	Full Operational Capability
FSOC	Fairchild Satellite Operation Center
FUV	Far Ultra Violet
FY	Fiscal Year

G

g	Gram
Ghz	Gigahertz
GFE	Government Furnished Equipment
GFO	GEOSTAT Follow-on
GOES	Geostationary Polar-orbiting Environmental Satellite
GPS	Global Positioning System
GPSR	Global Positioning System Receiver
GRC	General Research Corporation

H

HEPS	High Energy Particle Spectrometer
HF	High Frequency
HILAT	High Latitude
HiRDLS	High Resolution Dynamics Limb Sounder
HIRS	High Resolution Infrared Radiation Sounder
HRPT	High Resolution Picture Transmission
HSR	Horizontal Spatial Resolution

I

IA&T	Integration, Assembly and Test
IASI	Improved Atmospheric Sounder Interferometer
IAW	In accordance with
IDP	Interface Data Processor
IDPS	Interface Data Processing Segment
IJPS	Initial Joint Polar-orbiting Satellite System
IOC	Initial Operational Capability
IORD	Integrated Operational Requirements Document
IPACS	Integrated Polar Acquisition and Control System
IPO	Integrated Program Office
IPT	Integrated Product Team
IR	Infrared
ITOS	Improved TIROS Operational System

ITS	Interferometer Thermal Sounder

J

JARG	Joint Agency Requirements Group
JIC	Joint Intelligence Center; Joint Ice Center
JPS	Joint Polar-orbiting Satellite System

K

K	Kelvin
kg	Kilogram
km	Kilometer

L

LAI	
LANDSAT	Land Satellite
LAWS	Large Atmospheric Wind Sounder
LCC	Life Cycle Costs
LDA	Launch Deployment Authority
LEO	Launch and Early Orbit
LL	Low Light
LWIR	Longwave Infrared

M

m	Meter
mb	Millibar
MAGSAT	Magnetometer Satellite
MAS	Millimeterwave Atmospheric Sounder
MDR	Mission Data Recovery
MEPED	Medium Energy Proton and Electron Detector
MEPS	Medium Energy Particle Spectrometer
MET	Meteorological
METOC	Meteorological and Oceanographic
METOP	Meteorological Operational (Polar Satellite)
MHS	Microwave Humidity Sounder
MICM	Multi Variable Instrument Cost Model
MISS	Microwave Imager Sounder Sensor
MLS	Microwave Limb Sounder
MLV	Medium Launch Vehicle
mm	Millimeter
MMD	Mean Mission Duration

MOA	Memorandum of Agreement
MOE	Measure of Effectiveness
MOPITT	Measurement of Pollution in the Troposphere
MOPP	Mission-Oriented Protective Posture
MPSOC	Multi-Purpose Satellite Operations Center
MSI&T	Mission Systems Integration and Test
MSTRS	Miniature Satellite Threat Reporting System
MSU	Microwave Sounding Unit
MUA	Military Unique Applications
MW	Microwave
MWIR	Medium Wave Infrared

N

nm	Nautical Mile
NADIS	Neutral Atmospheric Daytime Ionosphere Sensor
NASA	National Aeronautics and Space Administration
NASEM	NPOESS Aerospace Systems Engineering Methodology
NATOPS	NATO Operations
NAVOCEANO	Naval Oceanographic Office
NBC	Nuclear, Biological, Chemical
NCEP	National Center for Environmental Prediction
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite, Data, and Information Service
NIC	National Ice Center
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NOARL	Naval Oceanographic and Atmospheric Research Laboratory
NOS	National Ocean Service
NOW	NOAA's Ocean Wave (model)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPR	National Performance Review
NSA	National Security Agency
NSTC	National Science and Technology Council
NWP	National Weather Prediction (model)
NWS	National Weather Service

O

O&I	Oceans and Ice
O&S	Operations and Support
OIPT	Overarching Integrated Product Team
OLS	Operational Linescan System

OMIS	Operational Multi-Spectral Imager Suite
OSD	Office of the Secretary of Defense
OSTP	Office of Science and Technology Policy
OTH	Over the Horizon
OTSR	Optimum Track Ship Routing
OWC	Ocean Wave Characteristics

P

P_k	Probability of Kill
PA&E	Program Analysis and Evaluation
PACS	Polar Acquisition and Control System
PAVE PAWS	(early warning radar system)
PBR	Playback and Record
PCA	Polar Cap Absorption
PDD	Presidential Decision Directive
PDDR	Program Definition and Risk Reduction
PEM	Program Element Monitor
PGM	Precision Guided Missiles
POE	Program Office Estimate
POES	Polar-orbiting Operational Environmental Satellite
P^3I	Pre-Planned Product Improvement

Q

R

R&D	Research and Development
RAO	Resource Analysis Office
RCM	Requirements Correlation Matrix
RDR	Raw Data Record
RDS	Real-time Data Smooth
RDT&E	Research, Development, Test and Evaluation
ROTHR	Relocatable Over The Horizon Radar
RPA-D	Retarding Potential Analyzer and Drift (meter)
RTD	Real Time Data
RTS	Remote Tracking Station

S

SAC	Strategic Air Command
SADARM	Sense and Destroy Armor
SAMP	Single Acquisition Management Plan

SARSAT	Search and Rescue Satellite
SATCOM	Satellite Communications
S&F	Store and Forward
S&R	Search and Rescue
S&SE	Solar and Space Environment
SBUV	Solar Backscatter Ultraviolet Spectral Radiometer
SCM	Spacecraft Cost Model
SDF	Surface Data Collection
SEER	System Evaluation and Estimate of Resources (model for software estimation)
SEM	Space Environment Monitor
SE/PM	Systems Engineering/Program Management
SES	Space Environment Suite
SESS	Space Environment Sensor Suite
SICM	Scientific Instrument Cost Model
SM	Soil Moisture
SOC	Satellite Operations Center
SOCC	Satellite Operations Control Center
SONET	Synchronous Optical Network
SOPS	Satellite Operations Squadron
SOWM	Spectral Ocean Wave Model
SPD	System Program Director
SPO	System Program Office
SSCM	Spacecraft Subsystems Cost Model
SSH	Sea Surface Height
SSH/T	Sea Surface Height/Topography
SSIES	Special Sensor Ionospheric Plasma Drift/Scintillation Meter
SSJ5	(Precipitating Electron/Proton Spectrometer)
SSM	(Triaxial Fluxgate Magnetometer)
SSM/I	Special Sensor Microwave/Imager
SST	Sea Surface Temperature
SSTP	Solid State TOMS Profiler
SSU	Stratospheric Sounding Unit
SSULI	Special Sensor Ultraviolet Limb Imager
SSUSI	Special Sensor Ultraviolet Spectrographic Imager
STT	Small Tactical Terminal
SSW	Sea Surface Wind
STAR	System Threat Analysis Report
SWH	Significant Wave Height

T

TBD	To Be Determined
TCS	Telemetry and Command Subsystem
TDA	Tactical Decision Aids
TDRSS	Tracking Data Relay Satellite System

TEDD	Total Energy (Density) Detector
TESS	Tactical Environmental Support System
TIROS	Television Infrared Observation Satellite
TOA	Top of Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Topography Experiment for Ocean Circulation
TT&C	Telemetry, Tracking and Commanding
TY	Then Year

U

UARS	Upper Atmospheric Research Satellite
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
US	United States
USAF	United States Air Force
USCM	Unmanned Space Vehicle Cost Model
USD (A)	Under Secretary of Defense (Acquisition)
USD (A&T)	Under Secretary of Defense (Acquisition and Technology)
USG	United States Government
USN	United States Navy
UV	Ultra Violet

V

VFR	Visual Flight Rules
VHF	Very High Frequency
VIRSR	Visible Infrared Scanning Radiometer
VIS	Visible

W

W	Watt
WBS	Work Breakdown Structure
WS	Weather Squadron
W/T	Weapons/Tactical Decision Aids

COBRA 1997 UPDATE

EXECUTIVE SUMMARY

March 17, 1997

COBRA 1997 UPDATE

EXECUTIVE SUMMARY

This report presents a summary level view of the efforts and results of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Cost, Operational Benefit and Requirements Analysis (COBRA) 1997 Update.

1. INTRODUCTION

The 1997 COBRA updates the Phase 0 NPOESS COBRA, results of which were formally documented and delivered in June, 1996. The Phase 0 COBRA considered four alternatives from both a cost and an operational benefit perspective, based on guidance provided by OSD PA&E in November 1995. The operational benefit analysis was conducted from a qualitative perspective only. From this analysis, the Optimized Convergence System (OCS) was developed as the Integrated Program Office alternative. This alternative met all user requirements stated in IORD-I at the threshold level, except those deemed as P^3I requirements, while achieving the NPR mandated cost savings of $ 1.3 billion. The PDM II directed the IPO to further study the OCS and to evaluate a reduced-capability/lower cost alternative, developed by OSD PA&E in the COBRA update.

The following information presents a summary of the analysis completed for the 1997 COBRA update. This analysis differs from that completed for Phase 0 in that it addresses benefit primarily from a quantitative perspective for selected differences of the two alternatives considered.

2. DESCRIPTION OF ALTERNATIVES

There were two alternatives considered, the Optimized Convergence System (OCS) and an alternative developed by OSD PA&E (known as “ALT A” for the remainder of this report). The OCS was described in detail in the Cost Analysis Requirements Description Document (CARD) dated 31 December 1996. ALT A was characterized by assessing differences from the OCS system. The primary difference is the substitution of less capable sensors in ALT 1. The OCS Cross-track Infrared Sounder (CrIS) and the Conical Microwave Imager/Sounder (CMIS) were replaced in ALT A by current or near-term sensors modeled after the High Resolution Infrared Radiation Sounder (HIRS)/3, Special Sensor Microwave/Imager (SSM/I), and Advanced Microwave Sounding Unit (AMSU)-B in ALT A.

3. LIFE CYCLE COST (LCC) ANALYSIS

As a milestone requirement, a Program Office Estimate (POE) for the OCS was completed by the IPO and reconciled with the estimate completed by the Air Force Cost Analysis Agency (AFCAA). With very few exceptions, the Program Office Estimate components were used to develop the Service Cost Position (SCP). As stated in a memorandum dated 28 February 1997 from the Chairman of the OSD Cost Analysis Improvement Group (CAIG), the CAIG had no issues with the NPOESS SCP and has deemed it reasonable for the baseline OCS program. The OCS estimate was used as a basis for developing the life cycle cost estimate for ALT A. Delta costs were developed, using the same methodologies used for the OCS cost estimate, for those areas impacted by the sensor changes described in the previous section. Table ES-1 provides the estimates for both alternatives at a summary level. There is approximately a $600M difference (FY96$) in the two alternatives, which equates to about $30M per year over the 20 year life cycle.

Table ES-1. Summary LCC Estimate Comparison, OCS and ALT A

[Table ES-1 has been deleted from this report since it contains Government Cost Information which may no longer be representative of the current NPOESS program.]

4. OPERATIONAL BENEFIT ANALYSIS

Performance differences between the OCS and ALT A were the focus of the operational benefit analysis. In this update, there were 21 EDR differences that varied at the attribute level (primarily vertical sampling interval, measurement accuracy and horizontal resolution). The 21 EDRs are shown in Table ES-2. Key EDRs are denoted by an asterisk.

Table ES-2. EDR Differences Between OCS and ALT A

EDR	EDR
1. Atmospheric Vertical Moisture Profile (AVMP)*	11. Cloud Top Pressure
2. Atmospheric Vertical Temperature Profile (AVTP) *	12. Fresh Water Ice Edge Motion
3. Imagery*	13. Ice Surface Temperature
4. Sea Surface Temperature*	14. Land Surface Temperature
5. Sea Surface Winds (speed and direction)*	15. Precipitable Water
6. Soil Moisture*	16. Precipitation Type/Rate
	17. Pressure (surface/profile)
7. Cloud Base Height	18. Sea Ice Age and Edge Motion
8. Cloud Ice Water Path	19. Snow Cover/Depth
9. Cloud Liquid Water	20. Surface Wind Stress
10. Cloud Top Height	21. Total Water Content

* Key EDR

Many NPOESS missions and measurement areas are impacted by the ALT A sensor changes that led to the EDR differences identified in the above table. Figure ES-1 shows the far reaching implications of these changes by mapping the OCS sensors to the EDRs, measurement areas and nine overall NPOESS mission areas. A boxed mission area indicates that it is addressed by one or more operational benefit analyses.

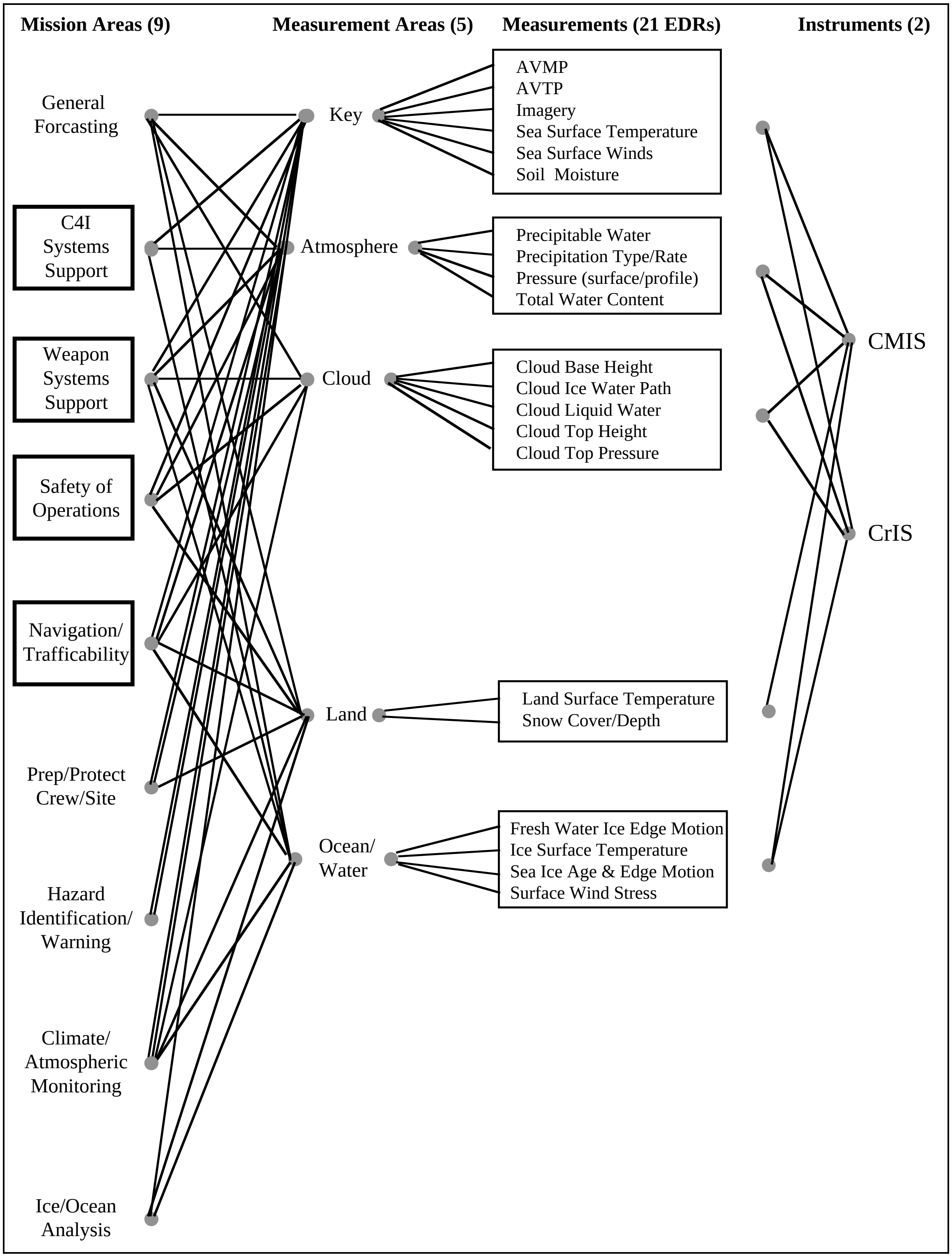

Figure ES-1. Sensor to Mission Mapping

The EDRs selected for analysis were chosen based upon two major criteria: stress to the system (key EDRs stress the system most) and ability to be analyzed with existing tools and data within the analysis timeframe. This led to the selection of six EDRs, three of which are key EDRs: Atmospheric Vertical Temperature Profile (AVTP), Atmospheric Vertical Moisture Profile (AVMP), Soil Moisture, Cloud Base Height, Precipitation Type/Rate, Pressure (Surface/Profile). Each of the EDRs is addressed by one or more studies. Summary results of the studies are provided in Table ES-3. Detailed documentation for each study is provided in Attachment A. Note that the precipitation study is ongoing and will not be presented in the attachment. NOAA results will be discussed in Section 5.

Table ES-3. Summary Operational Benefit Analysis Results

Strategic Area	Metric Explored	OCS Assessment	ALT A Assessment
	SUAG Assessment	Acceptable	Unacceptable
Fire Support	Normalized # of Munitions Predicted for EFD[1] =0.3: DPICM[2] SADARM[3]	 1 1	 3 2
Maneuver	Expected Forces Able to Traverse Grid[4]	100%	40%
Naval Operations	Assumed Radar Detection Range vs. EXOCET-class Missile [5]	59-74 nm[6]	15 nm
Mission Planning	Normalized NOWCAST Error Rate	1	2.7 (avg.)
Forecasts & Warnings		Acceptable	Significant Negative Impacts on Numerous Forecasts

1. EFD is Expected Fractional Damage
2. DPICM is the Dual Purpose Improved Conventional Munition
3. SADARM is Sense and Destroy Armor
4. One case only, one group of vehicles over one 140 x140 km grid with a single “dry” path
5. Assuming finer sampling interval allows you to see duct (OCS) and coarser sampling does not (ALT A).
6. Depending on scan elevation angle.

5. NOAA COBRA INPUT

NOAA has four major strategic areas supported by the NPOESS system: short-term warnings and forecasts, seasonal/interannual forecasts, decadal/centennial change and fisheries/coastal. The National Weather Service Strategic Plan is focusing on improving the short-term warnings and forecasts and extending the predictability to all weather elements.[1] To achieve this increase in forecast ability, the finer resolutions and measurement accuracies provided by the OCS system are needed, although the amount of improvement in forecast ability has not yet been related, in a quantitative sense, to a specific measurement improvement. Nowlin[2] states that a 60% increase in El Nino Forecast Skill will save the agricultural, fisheries, and forestry sectors of the U.S. economy from $ 0.5 Billion to $ 1.1 Billion per event. Another example of the benefit of such improvements is in hurricane forecasting. Benefits of better data from a CMIS instrument would include developing better estimates of time of landfall, location, storm intensity, and precipitation amounts. Better understanding of this type of storm enables the authorities to be more focused in evacuation efforts (i.e., better understanding of which areas should and shouldn't be evacuated) and provides a more realistic planning timeframe for those affected (including relief organizations) by these storms. An increase in the Hurricane Landfall Forecast Skill is estimated to save one million dollars per mile.

NOAA has undertaken several multi-year studies (Observing System Simulation Experiments) to better understand the improvement to forecasting/prediction and the associated economic benefits which result from improvements to the spaceborne instruments. The IPO will analyze the results of these studies to determine what additional cost/performance tradeoffs can be made in the NPOESS program.

6. CONCLUSIONS

[1] Office of Meteorology 1996-2005 Strategic Operating Plan
[2] Nowlin, Bulletin of the AMS, Vol 77, No 10, Oct. 1996, pg. 2244.

These analyses have shown a measurable improvement in operational effectiveness of the OCS over ALT A for the limited EDRs/missions studied. Given that the potential exists for these and even greater benefits across a broad spectrum of military and civilian needs (as seen in Figure ES-1), the users have concluded that it is worth the additional money to achieve these benefits resulting from improved data from the OCS. PA&E has concurred with this conclusion and stated at the 4 March 1997 OIPT that there is “no compelling reason not to continue with Optimized Convergence.”

7. REFERENCE DOCUMENTATION

Table ES-4 provides a list of reference documents and attachments relevant to this report.

Table ES-4. Reference Information

Document	Status
IORD-I	Provided under separate cover (3/96)
COBRA Phase 0 Report	Provided under separate cover (6/96)
Cost Analysis Requirements Document	Provided under separate cover (12/96)
Cost Documentation (POE, SCP, etc.)	Provided to PA&E (Feb. 1997)
Operational Benefit Study Summaries	Attachment A

ATTACHMENT A

COBRA '97 UPDATE

OPERATIONAL BENEFIT RESULTS

March 17, 1997

A.1 AVTP, AVMP and Pressure Effects on Fire Support

The following describes the analysis completed by the U.S. Army Field Artillery School at Fort Sill, Oklahoma regarding AVTP, AVMP and Pressure EDRs. Please note that many details of this study are not presented here due to the classification level of this report. As necessary, these details can be provided by Ft. Sill under separate cover and at the appropriate classification level.

Study Purpose

The purpose of this study is to provide a quantitative comparison of impacts to weapons system support for two Army 155 millimeter artillery munitions, Dual Purpose Improved Conventional Munitions (DPICM) and Sense And Destroy ARMor (SADARM) based on environmental information from the OCS and ALT A polar-orbiting weather systems. These impacts are measured by the relative differences in numbers of munitions needed for destruction of specific targets.

Importance/Statement of Problem

Information on temperature, moisture and pressure impacts the delivery accuracy of various weapon systems. Errors in the measurement of these environmental parameters can lead to inaccurate estimates of numbers of munitions required for target destruction based on inaccuracies in the assessment of the delivery accuracy of the weapon system to be used.

Mission

The weapon system support mission under the Army fire support strategic area is supported by the environmental information studied in this analysis.

Scenario

Scenarios and geographical areas were examined in which there was a primary reliance on polar-orbiting satellites for weather data (i.e., infrastructure/weather stations did not exist or could not be brought by entering forces in the timeframe considered). It was assessed that this would have to be an early-entry situation. The planning guidance was reviewed and two Major Regional Contingencies (MRCs) were examined, MRC-East and MRC-West. The first 40 hours of an MRC-West was chosen since there were no existing weather stations in this area and it was assumed there would be only limited meteorological data collection equipment that could be brought with the early forces, making it necessary to rely almost solely on the polar-orbiting NPOESS satellites. Blue (i.e., friendly) forces were assumed to be using an extended range 155 millimeter Howitzer shooting Dual Purpose Improved Conventional Munitions (DPICM) and the Sense And Destroy ARMor (SADARM) against several different targets described in the Methodology and Data (Threat Analysis) section, below.

Capability Differences (EDR Addressed)

Three EDRs were examined that impacted delivery accuracy of the DPICM and the delivery accuracy of the SADARM. The attribute that has the most impact is measurement accuracy at lower regions of the atmosphere. Table A1-1 presents the EDRs examined with the attribute levels for the ALT A and OCS systems.

Table A1-1. EDRs Addressed

EDR	Attribute	Units	Threshold	OCS	ALT A	Delta Increase from OCS
AVMP						
	Meas. Acc (600-400 mb, clear)	%, +/-	35	20	35	75%
AVTP						
	Meas. Acc (sfc-300mb, clear)	K/1km layer	1.6	1.0	1.6	60%
Pressure						
	Meas. Acc (0-10 km)	%, +/-	5	5	18	260%

Tools Used

Two primary tools were used, ARTQUIK and GENESIS. The ARTQUIK is a simplified deterministic Artillery Projectile Model developed and maintained by the Joint Munitions and Effectiveness Methodology (JMEM) DoD Working Group. ARTQUIK computes Expected Fractional Damage (EFD) as a function of the number of rounds of high explosive and/or DPICM fired. Variable input parameters include: target, target range from firing systems, target location error, target size, target environment, type of munition and system delivery errors.

The Generic Smart Indirect Fire Simulation or GENESIS model is a monte carlo simulation tool developed by ITT Research Institute for Smart Weapons Management Office of the U.S. Army Materiel Systems Analysis Agency (AMSAA). It is used to assess the “end-game” effectiveness of smart artillery munitions (e.g., SADARM). GENESIS allows the user to design the target with the appropriate equipment necessary to evaluate submunition effectiveness against each target. The model also has the ability to place false targets as countermeasures to these smart submunitions.

Methodology and Data

There are three major methodology components of this study: threat assessment, qualitative analysis and quantitative (performance) analysis. Each will be discussed separately.

Threat Assessment

Based on the information discussed under the scenario assessment, specific target sets that U.S. artillery would be facing on the ground were determined. At an unclassified level, there were four targets examined for the DPICM -- a Command Post, a Towed Howitzer Battery, a Mechanized Infantry Company, and a Self-Propelled Howitzer Battery. Three targets were examined for the SADARM: a Tank Company, a Mechanized Infantry Company, and a Self-Propelled Howitzer Battery.

Qualitative Analysis

A qualitative analysis was conducted to assess the individual meteorological (MET) parameters delivered by the two candidate systems that impact current and projected artillery systems. Various literature searches were conducted and subject experts in the field artillery school and in program offices as well as operational representatives were contacted. Of the 20 EDRs of difference between OCS and ALT A, eleven (11) affect artillery system performance in several areas including delivery accuracy, submunition performance, target acquisition, mobility, trafficability, ballistic computation, and mission planning for nighttime operations. The 11 EDRs are Atmospheric Vertical Moisture Profile (AVMP), Atmospheric Vertical Temperature Profile (AVMP), Cloud Base Height, Cloud Ice Water Path, Cloud Liquid Water, Cloud Top Height, Cloud Top Pressure, Land Surface Temperature, Precipitable Water, Precipitation Type/Rate, and Pressure. Due to the time constraints placed on this study, we were able and chose to focus the analysis on delivery accuracy (i.e., getting the munition to the target). The three environmental parameters that impact this area are AVMP, AVTP and Pressure as were shown in the "capabilities differences" section.

Quantitative Analysis

A quantitative analysis was conducted to assess the performance effectiveness of the limited set of EDRs that directly affect the ballistic computation of artillery. The result of the analysis is a comparative assessment of the number of rounds needed to achieve a specific level of fractional damage against the standard artillery targets discussed under the "threat assessment" section. Several steps were taken to develop the quantitative results including error budget assessment, error budget modification, and running the models with this information. These steps are described below.

Error Budget Assessment

Delivery accuracy is key to artillery performance. Delivery accuracy data for various artillery systems and artillery fired munitions are provided by an AMSAA database. For this study, the delivery accuracy for an extended range 155 millimeter cannon system (that shoots both the DPICM and SADARM munitions) was chosen based on relevancy to the scenario and time constraints on the analysis. The delivery accuracy is broken down into several components, as shown in Figure A1-1. An explanation of each component is provided below in Table A1-2. This analysis focused on changes to the meteorological component for the bias portion of the error, in an “NPOESS-only” situation. The precision error was held constant for the alternatives since it is very minor in comparison to the bias error. In addition, the EDR attribute differences between the alternatives would not effect the change in the meteorological component of the precision error.

The meteorological component for both range and deflection is broken down into temperature, wind and density subcomponents. Based on AMSAA data (the 155mm Howitzer Accuracy and Effectiveness Analysis (12/93)), the average distribution of this data is approximately 18% temperature, 55% wind, and 27% density. This distribution was assumed for this study. As neither alternative measures wind to sufficient accuracy levels to consider this component in this study, wind was kept constant for each alternative. Also, the fact that wind was kept constant did not allow us to consider the drift component of error relevant to the SADARM submunition performance.

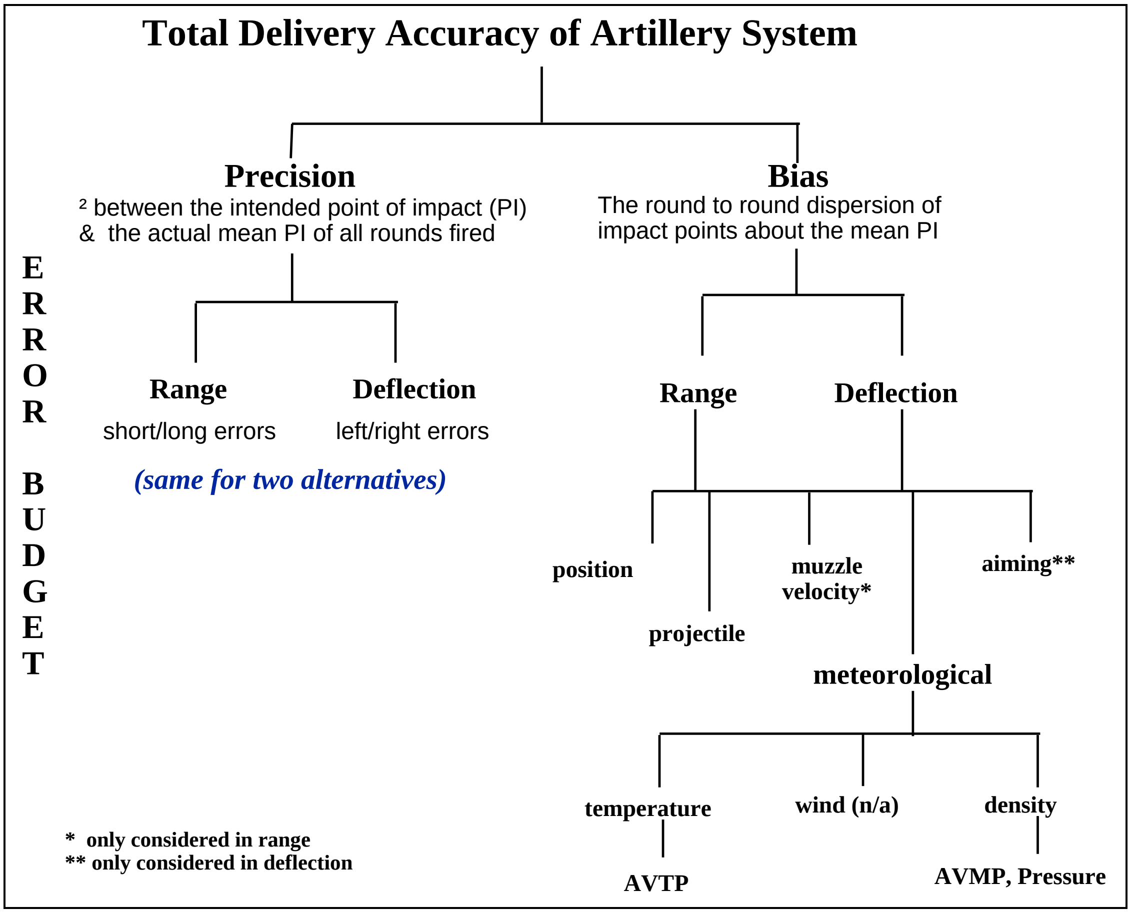

Figure A1-1. Delivery Accuracy/Error Budget Components

Table A1-2. Explanation of Error Budget Components

Error Budget Component	Explanation
Position	Error associated with the ability of the fire unit to know its own location.
Projectile	Error associated with lift, drag, and tube memory.
Muzzle Velocity	Error associated with the ability to determine what is the muzzle velocity of the munition when it leaves the tube. (Understand delta from round to round.)
Meteorological	Error associated with meteorological information.
Aiming	Error associated with ability of the howitzer to understand where tube is pointed.

Error Budget Modification

Time did not allow AMSAA to generate updated temperature and density components for the extended range 155 millimeter cannon based on meteorological information from the two alternatives. In order to get this information, Ft. Sill analysts used subject expert judgment to estimate these at the lowest level to reflect the relative differences in the two alternatives. Since at the unclassified level, only relative differences were at issue, the baseline estimates for the temperature and density components (range and deflection) were developed to reflect the OCS system. These estimates, along with the wind component data from AMSAA, were used to develop the MET component of the error budget. The MET component is equal to the square root of the sum of each component (temperature, wind, and density) squared. In order to get the ALT A MET component estimate, the EDR attribute deltas shown in Table A1-1 were used to develop factors to apply to the OCS temperature and density baseline components. The factor was 1.6 for temperature since there was a 60% increase from the OCS to the ALT A measurement accuracy value for AVTP. The factor was 2.7 for density based on a rounded average of the differences in AVMP and Pressure (i.e., there is a 75% (1.8 factor, rounded) increase in AVMP measurement accuracy and a 260% (3.6 factor) increase in Pressure measurement accuracy. Taking the average leads to a factor of 2.7 [(1.8 + 3.6)/2]). The wind estimate was held constant. The ALT A MET component is equal to the square root of the sum of each ALT A component (temperature, wind, and density) squared (as it was for OCS). Figures A1-2 and A1-3 present the error budgets for the OCS and ALT A respectively for the DPICM and SADARM. The numbers presented are one sigma errors in meters. The differences in temperature and density (and, therefore, in the MET component) lead to total budget difference of approximately +52% averaging range and deflection components. The total budget is the square root of the sum of the squares of the individual components.

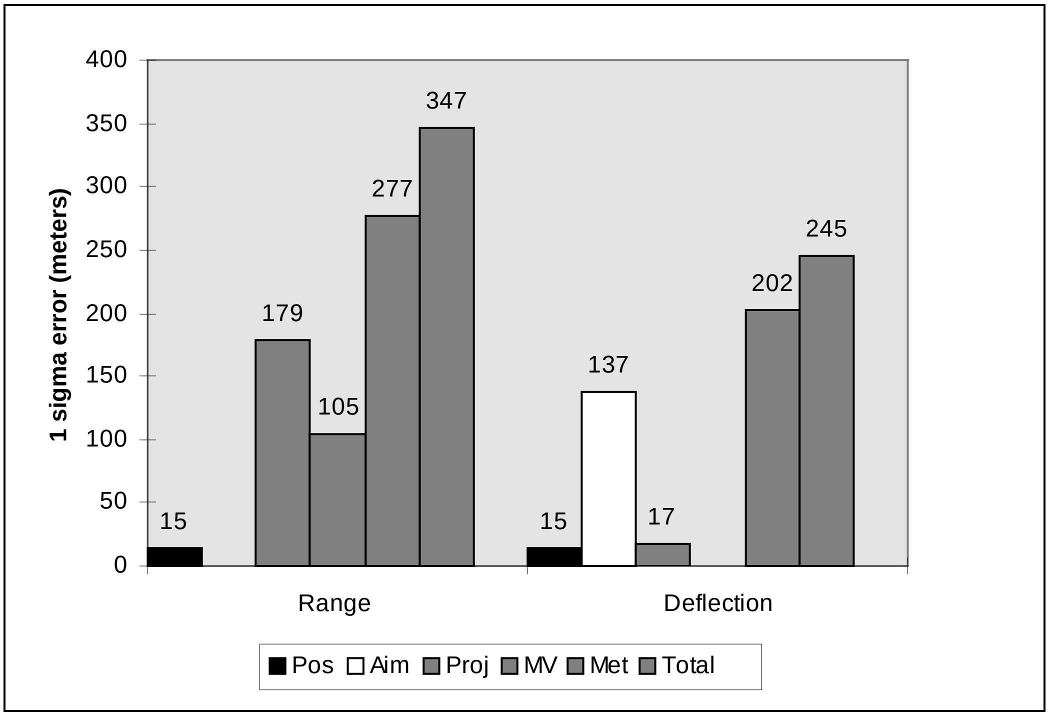

Figure A1-2. OCS Bias Error Budget for the DPICM and SADARM

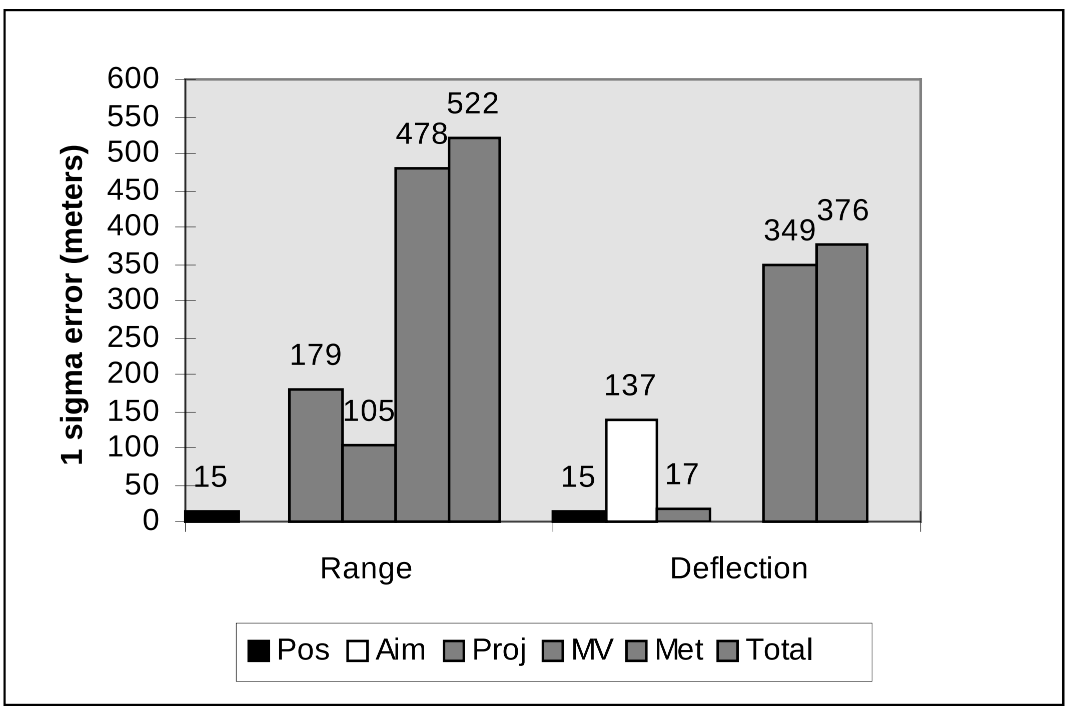

Figure A1-3. ALT A Bias Error Budget for the DPICM and SADARM

Running Models

The ARTQUIK and GENESIS models used the delivery accuracy/error budget information along with the description of the target variables described in the "Tools Used" section to output the number of munitions needed for a specific expected fractional damage (EFD) (i.e., the average fraction of target elements in the target area damaged by an expenditure of "N" rounds). The EFD was set to 0.3 which is the field artillery "standard" for destruction.

Results

As we have stated, the delivery accuracy drives the number of munitions needed to destroy a target. The models took these into consideration for the targets shown below and provided the number of munitions needed to achieve an EFD of 0.3. Due to the classified nature of these detailed results, they have been normalized for presentation here. Figures A1-4 and A1-5 present the results for the DPICM and the SADARM respectively. For the DPICM, approximately three times the number of munitions (rounded to the nearest whole number) would be expected to achieve the required EFD if ALT A system were providing weather information versus the OCS information. For the SADARM, approximately two times the number of munitions would be expected to achieve the required EFD if the ALT A system were providing weather information versus the OCS information.

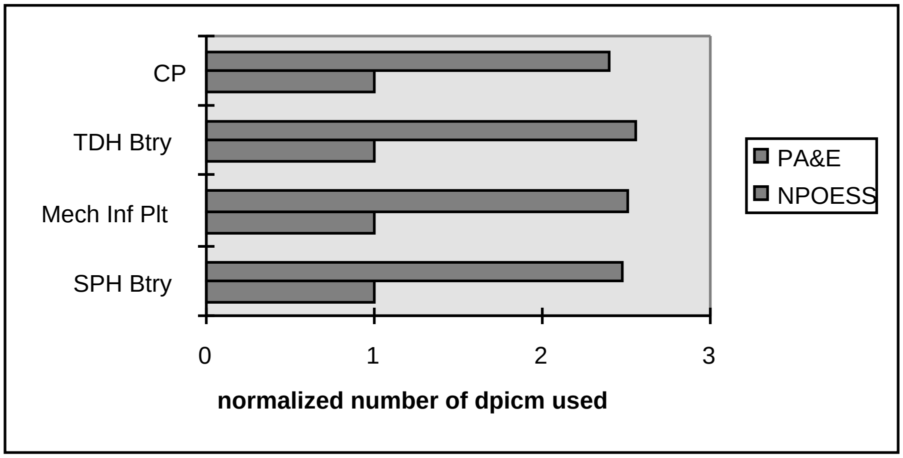

Figure A1-4. DPICM Required for EFD = 0.3 for Four Target Sets

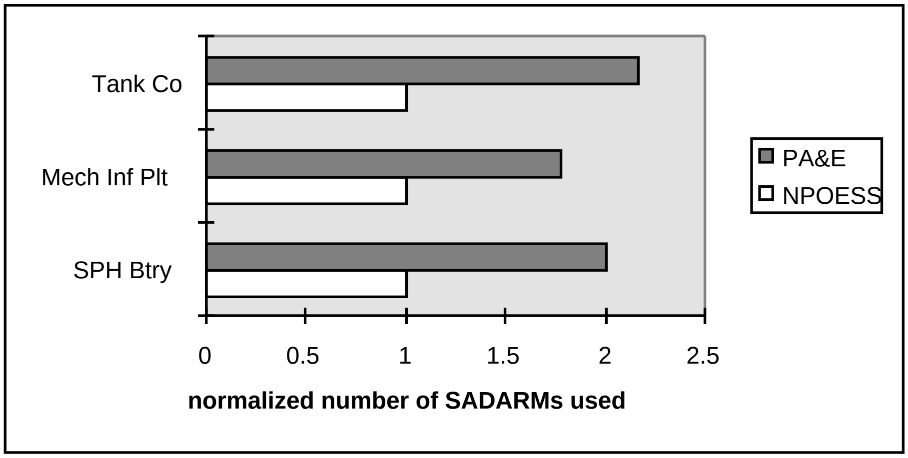

Figure A1-5. SADARM Required for EFD = 0.3 for Three Target Sets

Conclusions

In this analysis we have only provided results for two distinct munitions. It is expected that results would be similar for various other munitions. Extending these results to an entire battle, one can see that there could be significant inefficiencies in munitions planning/resource allocation (carry more weapons than you actually need, go after fewer targets with a specific munitions cache, lost opportunities due to expected heavy munitions expenditure, etc.) if one has to rely on less accurate weather information (i.e., use the ALT A system).

The Future

Due to limited time and resources, many munitions and EDRs could not be studied (as we previously discussed, we were only able to study three out of the 11 EDRs of difference) that affect artillery system performance. It is the intention of the IPO to continue analysis to include additional EDRs, munitions and scenarios. In addition, all analyses would be extended to force-on-force situations with the Target Acquisition Fire Support Model (TAFSM). With TAFSM, battle-level measures of effectiveness (MOEs) such as “number of red (i.e., foe) losses” and loss-exchange ratios could be calculated. The STRIKE model would be used to address other smart weapons not addressed in the GENESIS performance analysis of this study.

A.2 AVMP Effects on Naval Operations

The following describes an analysis completed by GRCI regarding Atmospheric Vertical Moisture Profile (AVMP) and the use of these profiles to identify areas where ducting occurs.

Study Purpose

The purpose of this study is to illustrate the impact of a coarser (50 mb) versus a finer (20 mb) Vertical Sampling Interval (VSI) in Atmospheric Vertical Moisture Profile (AVMP) measurements to radar detection range by an AEGIS-class radar for an EXOCET-class missile.

Importance/Statement of Problem

AVMP is a critical input to the calculation of atmospheric refractive index for microwave/radar performance predictions. The refractive index is a measure of refraction, which refers to "the property of a medium to bend an electromagnetic wave as it passes through the medium"[1]. "In free space, an electromagnetic wave will travel in a straight line because the index of refraction is the same everywhere. Within the earth's atmosphere, however, the velocity of the wave is less than that of free space...", causing the propagating wave to bend downward from a straight line. [2]

Under standard or normal atmospheric conditions, the gradient of the refractive index profile is predictable and, therefore, its impact on radar performance can be calculated. Problems arise, however, under conditions where the refraction index changes in a non-standard way so that its impact on radar performance would not be anticipated. An example of such a condition would be an inversion layer which gives rise to an atmospheric duct. A duct is defined as "a channel in which electromagnetic energy can propagate over great ranges."[3] This channel acts as a waveguide and is a result of the

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[1] Engineer's Refractive Effects Prediction System (EREPS), Version 3.0, Naval Command, Control and Ocean Surveillance Center, May 1994.
[2] Ibid.
[3] Ibid.

refractive index gradient changing faster with altitude than it would under normal conditions. There are different types of ducts, such as evaporation and surface-based ducts, and several meteorological conditions driven by moisture and temperature changes that can lead to these ducts[4] (Note: Refractive index changes and, hence, radar ray propagation characteristics, are driven by changes in atmospheric vertical moisture and temperature profiles. A common condition over the ocean which causes a duct to occur is an inversion layer where there is a rapid change in temperature and humidity profile over a small altitude regime.)

The presence of a duct can significantly alter radar performance. "Ducts not only give extended radar detection or Electronic Support Measures (ESM) intercept ranges for systems within the duct, they may also have a dramatic effect upon transmitter/receiver systems that transcend duct boundaries. For example, an air target that would normally be detected may be missed if the radar is within or just above the duct and the target is just above the duct."[5] In this case, the duct would trap most of the energy from the radar and lower the detection probability for a target outside the duct. Figure A2-1 illustrates this concept.

[4] Ibid.
[5] Ibid.

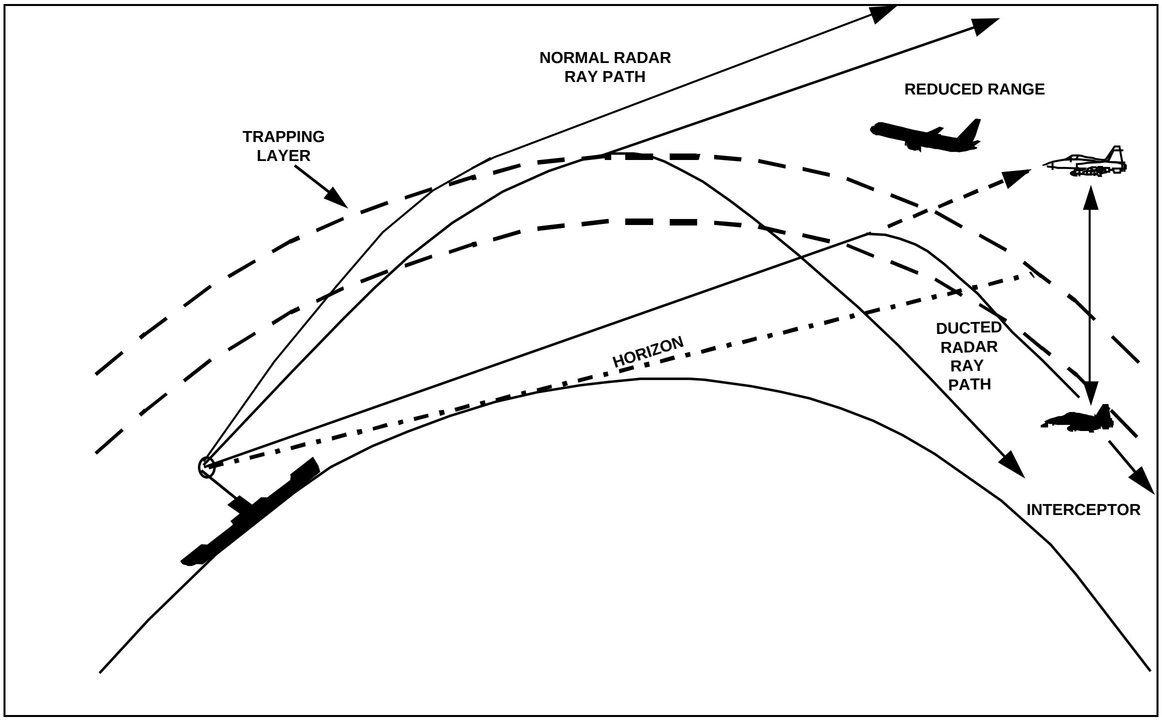

Figure A2-1: Ducting Consequences[6]

With atmospheric vertical moisture content being critical to the creation of ducts, it is important to measure the vertical profile of moisture as accurately as possible to determine where rapid or unexpected changes occur. This can be achieved with finer AVMP vertical sampling interval measurements.

Missions

The primary mission supported are Weapons and C4I systems support, in this case, for Naval operations.

Scenario

The location of interest is the Straits of Hormuz. The scenario is an AEGIS Class shipboard radar searching for an incoming EXOCET-class cruise missile flying 20 meters above the water. There is an evaporation duct at 15 meters and a surface-based duct at

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[6] Ibid.

176 meters. (Climatology data shows that, for this location, 50% of all evaporation ducts heights are less than 14 meters, and 58% of surface-based ducts are at 176 meters.[7])

Capability Difference (EDR Addressed)

The EDR addressed is AVMP. The specific attribute analyzed is vertical sampling interval. For the OCS, the vertical sampling interval is 20 mb for surface - 850 mb, versus 50 mb for ALT A within this same section of the atmosphere. Sampling intervals for all other sections of the atmosphere are the same for the two alternatives.

Tools Used

The primary tool used is the Engineering Refractive Effects Prediction System (EREPS), developed by the Naval Command, Control and Ocean Surveillance Center. EREPS is "a system of individual stand-alone IBM/PC-compatible programs to aid an engineer in properly assessing electromagnetic (EM) propagation effects of the lower atmosphere on proposed radar, electronic warfare, or communication systems. The EREPS models account for effects from optical interference, diffraction, tropospheric scatter, refraction, evaporation and surface-based ducting, and water vapor absorption under horizontally homogeneous atmospheric conditions."[8] EREPS is an engineering tool version of an operational program called the Integrated Refractive Effects Prediction System (IREPS). Both programs use standard propagation models so that the results obtained in this study should be consistent with results obtained in the field.

One of the EREPS programs (PROPR) calculates and displays signal-to-noise ratio in a decibel versus range diagram. GRCI used this program to display the consequences of "seeing" versus "not seeing" a duct in terms of extended radar detection range. EREPS also provides global information on the position and frequency of occurrence of ducts.

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[7] Ibid.
[8] Ibid.

Methodology and Data

An example refractive index profile[9] was used to illustrate how the larger 50 mb sampling interval (ALT A) would miss a duct occurring at a height of 467 meters. EREPS was then used to illustrate an example of the consequences of missing a similar duct (i.e., a surface-based duct) occurring at an altitude consistent with normal conditions for the Straits of Hormuz. This is done by implementing the EREPS tool with the specific characteristics of the AEGIS-class radar and the EXOCET-class cruise missile (such as radar cross section) and the presence of an evaporation duct (at 15 meters) and a surface-based duct (at 176 meters). The output (Figure A2-2) shows the impact in detection range when the duct is identified and when it is missed.

Results

Table A2-1 below is an actual modified refractive index profile.[10] Note that the sample shows that the modified refractive index, M, is increasing with height except for a slight decrease at the 467 meters reading, which indicates the presence of a surface-based duct.

Table A2-1. Actual Modified Refractive Index Profile[11]

Pressure (mb)	Altitude (m)	Modified Refractive Index (M)
1013	0	376.7
1005	10	376.7
1000	57	373.5
975	276	410.8
954	467	409.5
933	660	414.2
850	1468	498.6
758	2433	622.6
700	3095	713.1

[9] Proceedings: Conference on Microwave propagation in the marine boundary layer 21 - 22 Sept. 1988, p. 2 - 131.
[10] Ibid.
[11] Ibid.

From the above empirical data, OCS and ALT A profiles are interpolated, using the interval size of 20 mb for the OCS and 50 mb for the ALT A. The results appear in Table A2-2. First note that, in the area of interest, surface to 850 mb, the OCS VSI size provides 9 readings, whereas the coarser interval with ALT A provides only four. Notice also that the duct at 476 meters is captured in the OCS profile as a change in the M gradient in that region. The single reading from ALT A in that region is not sufficient to isolate this phenomenon. (A key assumption in this study is that a system which can see ducts would allow a ship captain to position his vessel to take advantage of the duct to extend the detection range for low flying threats.)

Table A2-2. Example OCS and ALT A Modified Refractive Index Profile Based on VSI Differences Between Surface and 850 mb

OCS VSI Profile			ALT A VSI Profile		
Pressure (mb)	Altitude (m)	Modified Refractive Index (M)	Pressure (mb)	Altitude (m)	Modified Refractive Index (M)
1013	0	376.7	1013	0	376.7
990	149	383.4	-	-	-
970	323	414.5	-	-	-
950	506	408.7	960	414	412.1
930	690	416.1	-	-	-
910	879	431.2	910	879	431.2
890	1072	450.8	-	-	-
870	1268	473.7	860	1367	486.0
850	1468	498.6	-	-	-

The above example shows that the larger 50 mb sampling interval of the ALT A system allows for more opportunities to miss critical phenomena (i.e., inversions which cause ducts) that occur between the surface and 850 mb. The EREPS output (Figure A2-2) shows an example of the consequences of missing a duct. This figure shows the signal to noise ratio versus range for the Straits of Hormuz scenario identified earlier in this section, for three cases: 1) no ducts; 2) evaporation duct only at 15 meters; and 3) evaporation duct at 15 meters and surface-based duct at 176 m. (Recall that the 176 meters height is chosen since it occurs most frequently (58% of the time) in the Straits of Hormuz.)

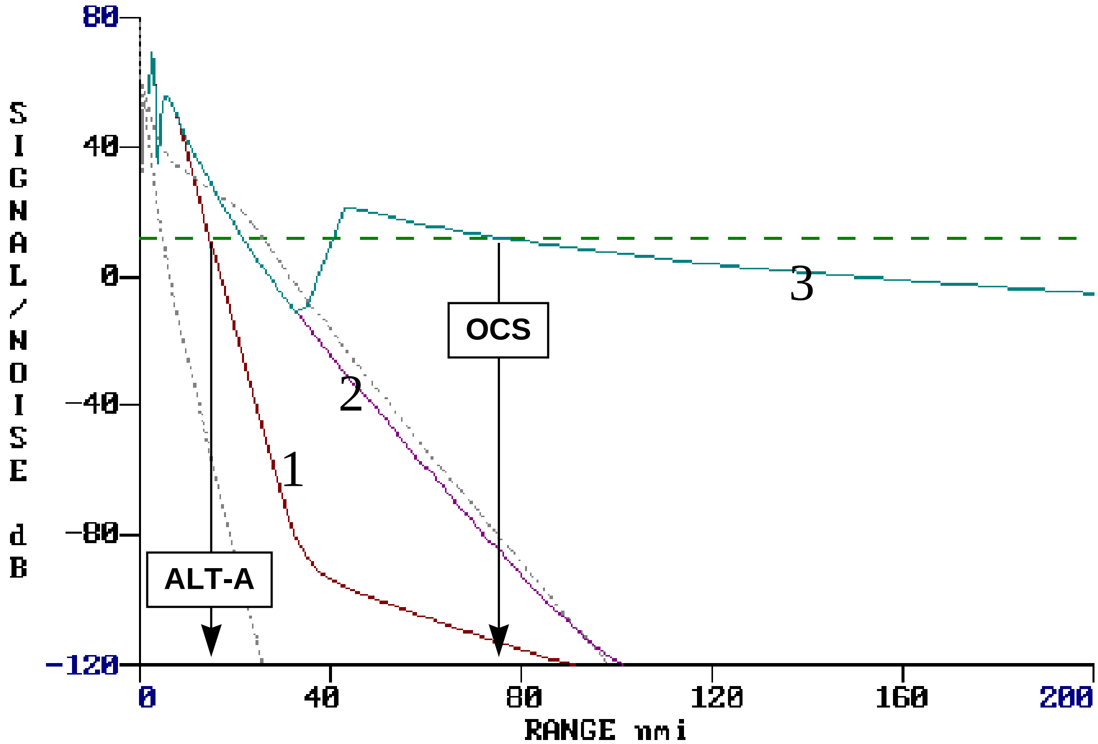

Figure A2-2. Signal to Noise Ratio vs. Range for Three Duct Profiles

Given that with the ALT A system, it is more likely that the coarser sampling interval would not pick up the surface based duct, a radar detection range of approximately 15 nm would be assumed to occur in this area since the radar operator is unaware of the presence of any ducts. With the OCS, it is more likely that the duct would be identified due to more readings (vertical samples). If so, and if the data were incorporated into the radar propagation calculations, a more accurate assessment of a true detection range of approximately 74 nm would have been determined. (Note that it is unlikely either alternative would pick up the evaporation duct at 15 meters.) As an excursion, if the target height was increased to 120 feet (from the 60 feet in the previous example), the assumed detection range would be approximately 16 nm if the duct is not seen versus approximately 85 nm if the duct is identified.

Conclusions

If, for example, a ship's captain relied on the information from ALT A to plan his covert operations, he might place his ship close to shore while still radiating, assuming that it was safe to do so when in fact an enemy could detect his radar. Alternatively, under the OCS conditions, he would know that his electromagnetic susceptibility to being detected by the enemy would be extended and would proceed accordingly. In addition, operators are also able to use ducts to their advantage: hide, deploy other assets only where needed to fill gaps in radar coverage, etc. Thus, knowledge of the location of predicted or existing ducting conditions can have a major impact on tactical operations. Finer vertical sampling of moisture profiles can significantly increase the operator's awareness and understanding of these, and other, environmental phenomena of tactical importance.

An Example: Iranian Air Bus Shoot Down Incident

The role of surface ducting can be illustrated with the unfortunate incident surrounding the shooting down of a civilian airliner by the USS Vincennes.

On the 3rd of July, 1988, Iranian gunboats attacked merchant vessels in the Persian Gulf. At 6:41Z time the USS Vincennes was ordered to engage the gunboats. In post action analysis, meteorological conditions indicated the presence of a strong evaporation duct and surface-based duct up to about 458 feet, which enhanced the detection range of the AEGIS-class Vincennes. During the time of the engagement of the gunboats and the USS Vincennes, an Iranian Airbus loaded with civilians took off at Bandar Abbas, approximately 47 miles north of the location of the USS Vincennes in the Persian Gulf. Because of the ducting, the Vincennes' radar was able to detect the Iranian Airbus as it lifted off of the runway at Bandar Abbas but, unaware of the presence of the duct, the operator did not correctly interpret the situation portrayed on the radar display. As the air route south was directly over the USS Vincennes, the airbus continued after takeoff to proceed on its normal commercial air route, thus closing the distance between it and the USS Vincennes. The Vincennes was in the middle of a tactical engagement at the time and, for other reasons that have yet to be determined, mistakenly identified and tagged the Airbus as a hostile F-14. Mistakenly tagged and appearing to pose a threat, the order was given to engage the target and two missiles were fired.

Although microwave propagation anomalies or ducts were not ruled to be a major factor in actually tagging the Iranian airbus as a hostile craft, because the ducts were present they did contribute to the confusion. The conclusion from the investigation indicated that operators need to know the electromagnetic environment and how their systems respond to it.

A.3 Soil Moisture Effects on Army Equipment Maneuvers

The following describes the analysis completed by GRCI for Soil Moisture.

Study Purpose

The purpose of this study is to provide an example of the impact to mission planning for trafficability based on soil moisture information from the OCS and ALT A polar-orbiting weather systems.

Importance/Statement of Problem

Detailed knowledge of soil moisture is critical to determining trafficability of terrain by troops and trucks. Military decision makers must know trafficability of terrain for route planning, asset deployment and timing to meet objectives, as well as predicting similar actions by the enemy.

Soil moisture is affected by environmental factors such as precipitation, temperature, humidity and wind, and by geographical factors, such as slope and vegetation. For a given soil type, moisture content in the soil is the principal factor affecting soil strength, which determines the ability to sustain movement by vehicles. It is therefore desirable to know soil moisture as accurately as possible for a given area of military interest.

Missions

The navigation/trafficability mission affected by soil moisture data is under the Army strategic area of maneuver.

Scenario

No specific geographical location/military scenario was selected for this analysis. A generic soil type (clay) over a sample area size (140 km x 140 km) was examined.

Capability Difference (EDR Addressed)

The difference between the OCS and ALT A with respect to soil moisture is in horizontal resolution cell size. The OCS alternative provides a measurement which is the average soil moisture over a 40 kilometer cell at nadir under cloudy conditions (50 kilometer cloudy, worst case), whereas ALT A provides the average soil moisture over a 140 kilometer cell under similar conditions. The OCS capability represents the user requirements as stated in IORD I.

Tools Used

Results from the Soil Moisture Strength Prediction Model[12] (SMSPM) were used, showing the relationship between the minimum soil shear strength, called the Rated Cone Index (RCI), and the percent moisture content for numerous soil classes.

Methodology and Data

The RCI is a derived number that defines the trafficability of soils as a function of moisture. The Vehicle Cone Index (VCI) is defined as the minimum RCI that is required for that vehicle type to pass. RCI numbers are available for numerous types of soils, and VCI numbers are available for numerous types of vehicles. High mobility vehicles have lower VCIs, whereas low mobility vehicles have higher VCIs. Table A3-1 shows the VCIs associated with several vehicle types.

Table A3-1. Assumed Soil Strengths for Various Mobility Classes

VCI Range	Vehicle Type
20 - 29	1 - Snowmobile/Otter
30 - 49	2 - Armored Personnel Carrier
50 - 59	3 - Medium Tank
60 - 69	4 - 2.5 - Ton Truck
70 - 79	5 - 4-Wheel Drive Heavy Truck
80 - 89	6 - 1/2 Tone Trucks; Pickups
>100	7 - Rear-Wheel Drive Trucks

[12] Soil Moisture Strength Prediction Model, Waterways Experimental Station, Vicksburg, MS

Figure A3-1 shows data from the Soil Moisture Strength Prediction Model for clay soil. This figure shows the relationship between soil moisture content and RCI. Thus, for any of the given vehicles in Table A3-1, one can determine whether that vehicle can successfully travel through clay with a known moisture content. (In reality, there are several other factors, such as vegetation, slope of terrain, rivers, roads, etc., that also impact trafficability. However, for the purposes of this analysis, it is assumed that the area is homogeneous and vehicle trafficability is affected only by soil moisture.)

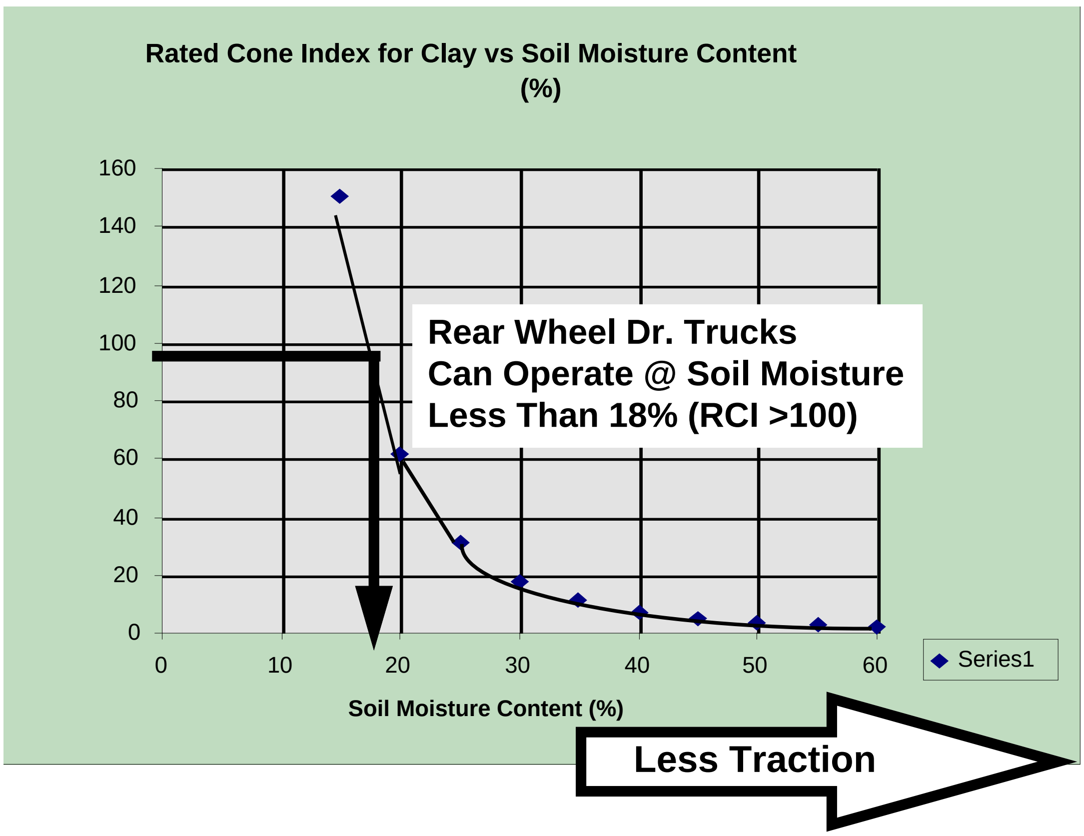

Figure A3-1. Rated Cone Index for Clay vs. Soil Moisture Content

Results

Figure A3-2 shows a sample grid of 140 km by 140 km, where the OCS alternative provides 16 measurements of soil moisture. In this figure, the white squares have a soil moisture content of 15% and the gray cells have a soil moisture content of 25%. Figure A3-1 shows that 15% soil moisture translates into an RCI greater than 140, allowing all the vehicle types in Table A3-1 to successfully maneuver through the cell. At a 25% soil moisture content, however, the RCI is down to approximately 30, allowing only armored personnel carriers (30<VCI<49) and the snowmobile/otter vehicle types (20<VCI<29) to successfully traverse through the cell. If each path to the objective is composed of four cells, it is clear that there is only one path that will allow all vehicle types to achieve the objective.

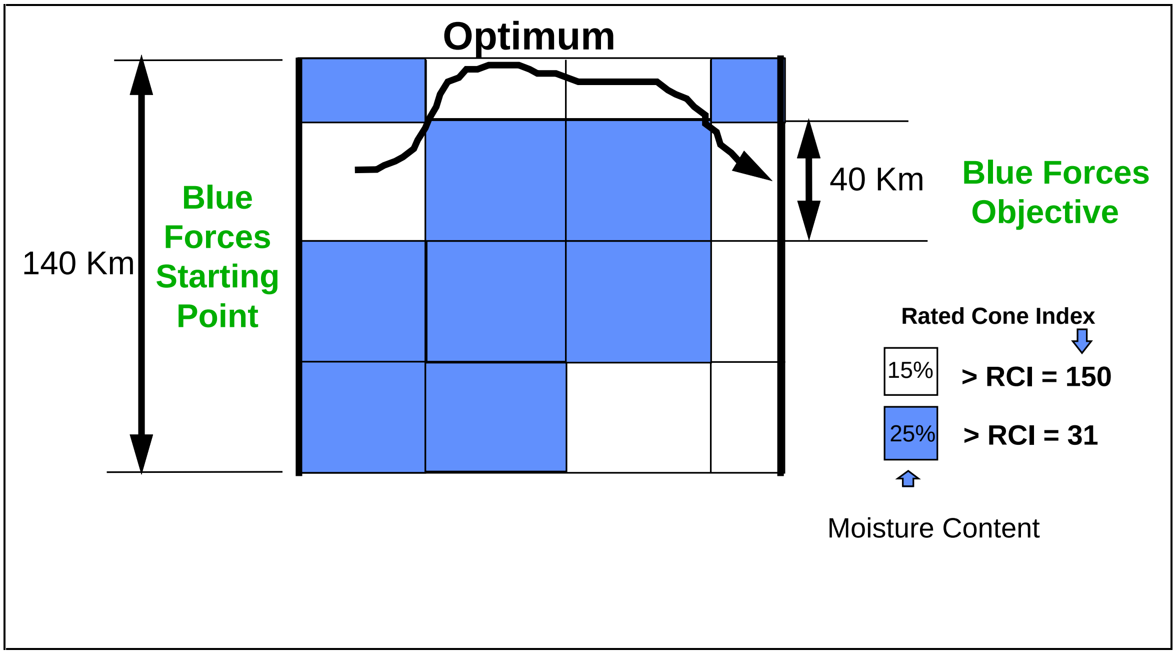

Figure A3-2. Example Area of Trafficability with Soil Moisture Known via OCS Alternative

Now assume that for ALT A, the only information the decision maker has is one averaged soil moisture measurement over the entire area. The average soil moisture is the weighted mean of the detailed cells, or approximately 21%, over the entire area, which translates into an RCI of approximately 55. With this limited knowledge, the decision maker can plan on only vehicles requiring a VCI of 55 or less to achieve the objective. Thus, based on the information in Table A3-1, only three vehicle types could be considered for deployment. As an example, if 1,000 vehicles are expected to cross the area and the vehicles are distributed as in Figure A3-3, under ALT A the decision maker can only plan on 40% of the forces arriving, whereas under the OCS alternative, the optimum path will be found and selected for trafficability of all 1000 vehicles.

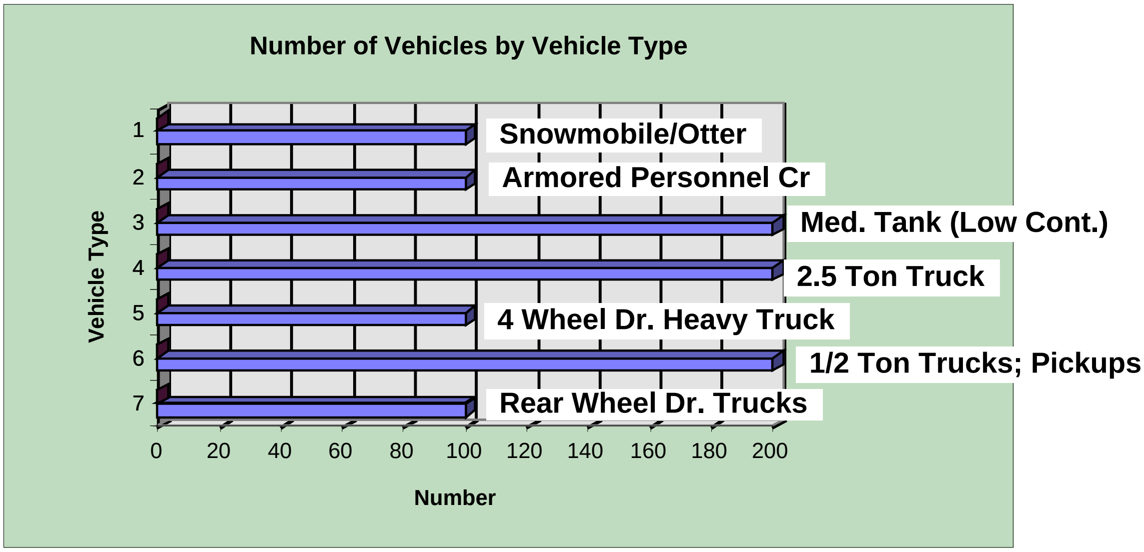

Figure A3-3. Example Distribution of 1000 Vehicles

Conclusions

The previous example illustrates the value of finer (horizontal) resolution soil moisture data to mission planning by allowing optimization of paths. The consequence of proceeding without this detailed knowledge, where unknown variations in soil moisture may exist and the “optimum” path for trafficability of all vehicles may not be easily identified, is that the decision maker is forced to rely on averages over a larger area which can subject troops and equipment to risks that could be controlled and/or avoided if better data were available. Similarly, with better data, the commander will understand how the enemy can attack and plan his defensive actions accordingly.

A.4 Cloud Base Height Effects on NOWCAST Error Rate

The following presents analysis by the Aerospace Corporation with regard to Cloud Base Height.

Study Purpose

The purpose of this study is to provide a quantitative comparison of impacts to mission planning for twelve Air Force weapons systems based on cloud information from the OCS and ALT A polar-orbiting weather systems. To do this we examined the NOWCAST combined false alarm and missed detection error generated by the Integrated Weather Effects Decision Aid (IWEDA) based on use of weather data from these two systems.

Importance/Statement of Problem

Mission planning for numerous airborne weapon systems is affected by knowledge of the clouds. Pilots and most smart weapons are dependent on cloud cover and ceiling NOWCASTs and forecasts to determine if weather conditions will allow the use of the weapon system for a particular mission. In most situations, pilots are required to obtain a visual sighting of the target to initiate weapons delivery, and "smart" weapons generally also require a clear line of sight to the target, i.e., unobstructed by clouds. NPOESS will supply data which will be used in IWEDA to produce these NOWCASTs and/or forecasts.

Mission

Weapons system support and safety of operations under the Air Force mission planning strategic area is supported by cloud information studied in this analysis.

Scenarios

NPOESS will be a significant contributor of weather data in all combat theaters, and for denied areas, i.e., in staging areas behind the enemy Forward Line of Troops (FLOT), it will be the only contributor. Both Belgrade, Serbia and Pyongyang, Korea were considered in this analysis since each is potentially representative of the situation described.

Capability Difference (EDR Addressed)

In our comparison of the OCS and ALT A systems, differences in performance are based strictly on the difference between the measurement accuracy and horizontal resolution of the Cloud Base Height EDR. Cloud coverage accuracy, while important to the analysis, is identical between the two alternatives since this EDR uses data from the Visible Infrared Imager Radiometer Suite (VIIRS) (common to both alternatives) and, therefore, was not considered in this study.

The OCS system attribute levels are based on using the temperature and moisture profiles available from CMIS to derive the height at which relative humidity reaches 100%, which is the height of the cloud base. Based on the expected accuracy of the CMIS for these profiles, the OCS will measure Cloud Base Height to +/- 500 meters or approximately 1640 feet (measurement accuracy) with a horizontal resolution of 15 kilometers in all weather. Note that the OCS will exceed IORD I threshold performance for this EDR, since other EDRs drive the CMIS performance to the level necessary to achieve the +/- 500 meter accuracy.

For the ALT A assessment, we also assumed that it would make use of temperature and moisture profiles to derive the height at which relative humidity reaches 100%, even though the cost of algorithm development needed for this is not included in our estimate of the ALT A cost. However, due to the much lower horizontal resolution of the AMSU across most of its swath, the measurement accuracy is degraded to +/- 2 kilometers, which is the IORD threshold value.

Tool Used

The Integrated Weather Effects Decision Aid (IWEDA) was developed by the Army Research Laboratory (ARL) to provide operational theater mission planning support for a number of weapon systems. It is a rule based expert system that transforms raw weather data into weather intelligence for the battle space commander.[13] It provides guidance on weapon utility as a function of the actual or forecast weather in the mission area by providing detailed information in terms of how, when, where, and why weather affects weapon systems (as well as their subsystems and components) and operations. This information is tailored to the end user and can provide detailed text explanations and geographic map overlays of what and where the impacts are, or simplified colored matrices providing information on when and why there are impacts[14] (i.e., based on information received from a weather system, the planner is told that there are no weather impacts (green), moderate weather impacts (yellow), or severe weather impacts (red) for a specific weapon system.) For our study, these colored matrices are what will be examined. In the most recent version of IWEDA a number of weapon systems from the Air Force and Navy inventory have been added, thus making it a fairly comprehensive weather effects planning tool. This is an operational tool that considers weather in the battle space, making it an ideal candidate for use in this study.

Methodology and Data

In this analysis, we looked at the expected difference between NOWCASTs made using the capabilities of the OCS baseline and ALT A for weapons which are affected by the coverage and base height of the cloud cover in the two areas of interest. Examining the IWEDA rules, we first looked at all weapons systems affected by these EDRs and then at the cloud base height and cloud cover "thresholds" for "yellow" (Y) and "red" (R) conditions. Note that both conditions must be "met" for the given "rating". These are shown in Table A4-1 below. Note that for this analysis, timeliness is not an issue since NOWCASTs require data that is not older than four to six hours and the refresh associated with either system accommodates this need.

[13] 1996 Battlespace Atmospherics Conference Abstract, D. P. Sauter, U.S. Army Research Lab.

[2] Ibid.

Table A4-1. Cloud Thresholds for Affected Weapon Systems

	Y				R		
System	Cover (>, eighths)		Base Height (<, feet)		Cover (>, eighths)		Base Height (<, feet)
A-10	3		3,000		5		1,000
AH-64	0		400		n/a		n/a
CH-47D	0		400		n/a		n/a
Copperhead	4		5,000		0		1,500
Copperhead	0		2,500				
EH-60A	0		400		n/a		n/a
F-15E	3		10,000		5		3,000
F-16	3		3,000		5		1,000
Hellfire-A	0		2,000		0		1,000
Hellfire-C	0		1,500		0		500
Maverick	0		3,000		0		1,000
Stinger	0		5,000		0		2,500
UAV	4		600		4		300

We compared the above data to the actual cloud cover and cloud base height data for 20 years for the two locations. We determined the fraction of time that two types of errors will occur for both OCS and for ALT A. The two error types considered were errors related to predicting a yellow condition and errors associated with predicting a red condition. In each case, the errors fall into two categories. The first is erroneously predicting a more stressing weather condition than actually exists, i.e., predicting yellow when the weather is actually green or predicting red when the weather is actually yellow. These errors are equivalent to a false alarm. The second category is predicting a less stressing condition than actually exists, i.e., predicting yellow when red exists or predicting green when yellow exists. These errors are equivalent to a missed detection. Due to the fact that the decisions rules in IWEDA use a threshold step between conditions rather than a graduated scale (see Table A4-1, above), the two categories are equally likely to occur, i.e., the error in a measured cloud base height value is as likely to occur above the threshold as below it.

For both cases the error computations were made using an expression for the probability of a decision error based on the actual cloud base heights for each site (Belgrade and Pyongyang), the measurement accuracy (+/- 0.5 kilometers for OCS and +/- 2 kilometers for ALT A), and on the threshold value (e.g., 3000 ft for yellow for the A-10, F-16, and Maverick as shown in Table A4-1). These error probabilities were then weighted by the frequency of occurrence of the cloud cover exceeding the cover needed to reach the condition (e.g., 3/8 cover for the A-10 and F-16, as shown in Table A4-1 above). The result of this is the frequency of occurrence of the combined error categories, i.e., false alarms and missed detections, for the two levels of cloud base height measurement accuracy.

Results

Note that, of weapon systems noted in Table A4-1, six of them showed no meaningful difference between the two alternatives due to the fact that the cloud base heights, which are sufficiently low, occur only a few percent of the time. These systems are: AH-64; CH-47D; EH-60; Hellfire-A; Hellfire-C; UAV. The remainder show significant weather susceptibility for these locations and consequently there is a significant difference in performance between OCS and ALT A. The results for these weapon systems are shown in Figure A4-1 for Belgrade and in Figure A4-2 for Pyongyang. For simplicity, the errors are shown normalized to the OCS performance. For example, in Belgrade ALT A would give 2.7 times the error frequency that OCS would give for NOWCASTs for an A-10 yellow condition. The minimum error rate for ALT A is approximately 2.5 for both scenarios.

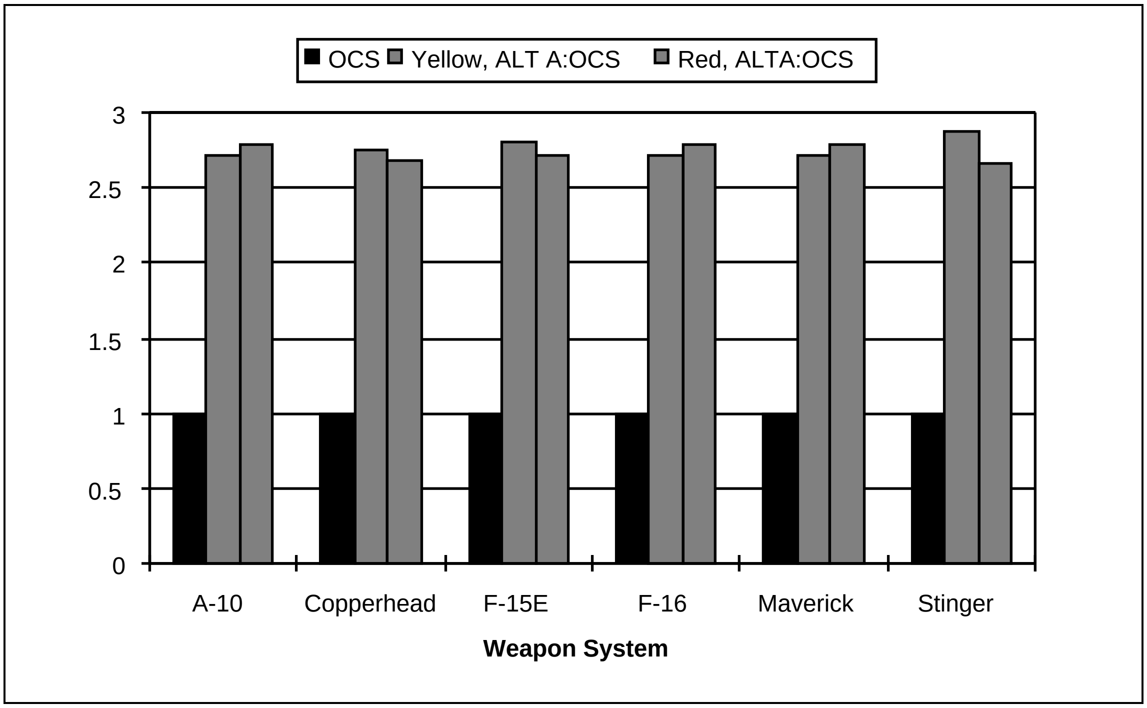

Figure A4-1. Belgrade NOWCAST Error Comparison

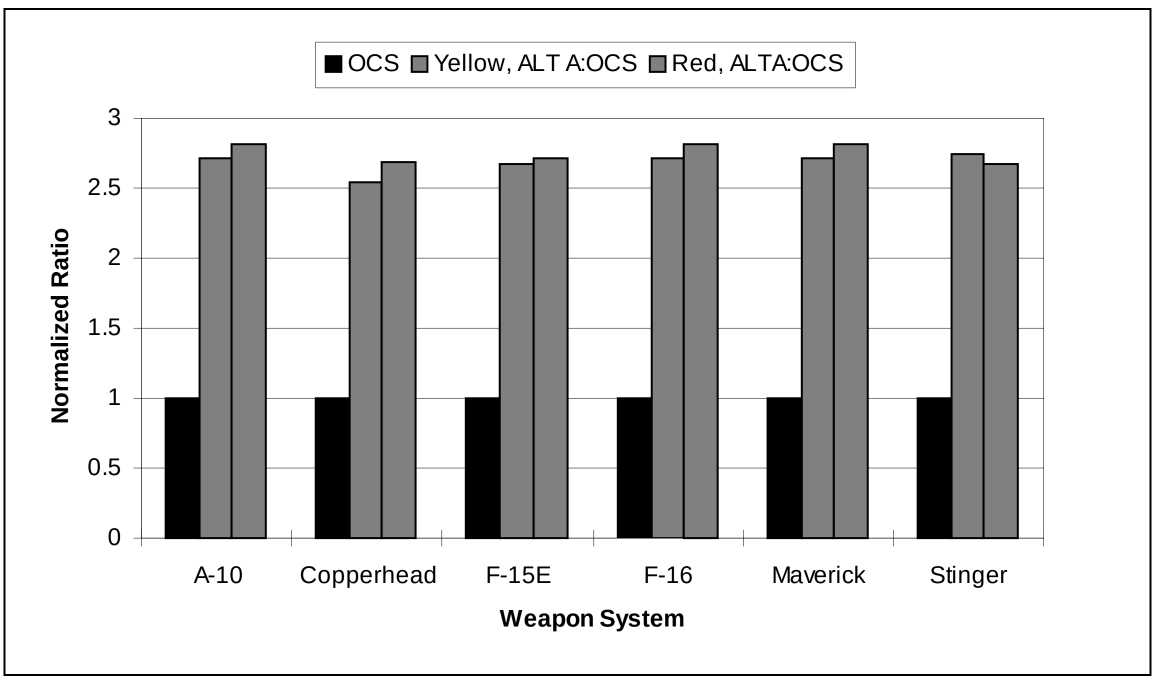

Figure A4-2. Pyongyang NOWCAST Error Comparison

Conclusions

The errors represented here impact mission planning in two different ways, the first is missed opportunities that result from false alarms (citing worse conditions than exist), the second is exposure to hostile forces resulting from missed detections (citing better conditions than exist). For the first case, ALT A would present significant weather constraints to the decision-maker when, in reality, they do not exist (or they exist to a lesser degree). This could have significant implications to weapon usage decisions (stand-down highly effective systems for the identified target sets) and/or unneeded delays/changes to existing mission plans both of which can significantly impact the success of the battle itself. For the second case, ALT A would allow sorties to occur that were completely unsuccessful due to the weather conditions or would require unexpected/unplanned diversions into potentially unknown and dangerous conditions (longer than required exposure to known/unknown hostilities).

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

Report on

Polar Convergence

Operational Benefits and Cost Savings

Prepared for the

House Appropriations Committee
for
Commerce, Justice, State, the Judiciary, and Related Agencies

by

The National Polar-orbiting Operational Environmental Satellite System
Integrated Program Office

February 2, 1998

Preface

This report is in response to a request contained in House Report 105-207 accompanying Commerce's FY1998 Appropriation Act.

Congressional Language[1]

During their review of the FY 98 Budget, the House Appropriations Subcommittee for Commerce, Justice, State, the Judiciary, and Related Agencies stated that there were still some issues associated with the NPOESS program which needed to be addressed. Accordingly, the Committee put the following text into their report.

> The Committee is concerned that the current program plan may not allow the original cost savings from convergence of $1,300,000,000 to be achieved. The Committee remains fully supportive of the polar convergence program (NPOESS), but is concerned about the implications of proposed significant upgrades for instrumentation, proposed early availability of satellites, and disproportional funding requests in the Departments of Commerce and Defense as included in the fiscal year 1998 budget submission. The committee believes that it is imperative that both Departments carefully review and prioritize NPOESS requirements, and encourages strong departmental oversight, to ensure that all expected benefits from convergence are realized. The Committee expects the Secretary of Commerce, not later than February 2, 1998, to submit a report on the current program plan and funding profile which details the operational benefits and cost savings to be achieved from convergence.

The Conference Report 105-405 states in part: "The conferees share the concerns expressed in the House report regarding the achievement of cost savings from Polar convergence. The conferees direct NOAA to follow the direction in the House report regarding this matter."

Background

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) resulted from White House and Congressional interest in converging the Department of Defense (DoD) and Department of Commerce (DOC) meteorological satellite systems into a more cost effective and higher performance integrated system than those in use today. The original goals were cost and efficiency driven (*e.g.*, to save at least $1.3B over planned follow-on systems per the National Performance Review[2] (NPR) guidance) while

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[1] House Appropriations Subcommittee for Commerce, Justice, State, the Judiciary, and Related Agencies, House Report 105-207 language in the "Polar Convergence" section under the "National Environmental Satellite, Data and Information Service"

[2] Creating A Government That Works Better & Costs Less (Department of Commerce); Accompanying Report of the National Performance Review, September 10, 1993; DOC 12: Establish a Single Civilian Operational Environmental Polar Satellite Program, (Fiscal Impact, pg. 56).

retaining the performance objectives of the requirements documents of the follow-on Defense Meteorological Satellite Program (DMSP Block 6) and the follow-on Polar-orbiting Operational Environmental Satellite (POES O,P,Q,R)[3] program. Furthermore, the NPR recognized that “the synergy achieved through DoD and NOAA cooperation could allow both agencies to meet critical operational requirements (such as collecting oceanographic and global tropospheric wind data) which neither agency has been able to afford alone.”[4] NPOESS is designed to maximize user satisfaction in terms of the requirements as currently specified in the NPOESS Integrated Operational Requirements Document (IORD-1)[5] while continuing to meet the cost savings goals of the NPR.

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[3] Estimates for the follow-on NOAA polar satellites (O, P, Q) were preliminary and were not fully costed out by NASA, NOAA’s procurement agent for the series. POES estimates have been adjusted to reflect costs associated with four spacecraft (O, P, Q, R) such that the life cycle costs reflect the same time frame for coverage as the NPOESS program. Use of these figures is for comparison of baseline cost purposes, and savings levels should thus be considered estimates.

[4] Ibid., Background, pg. 54

[5] Integrated Operational Requirements Document (IORD) I, National Polar-Orbiting Operational Environmental Satellite System (NPOESS), 28 March 1996

Executive Summary

[This paragraph has been deleted since it contained Government Cost Information which may no longer be representative of the current NPOESS program.]

Within this cost, the NPOESS program will be able to meet the validated users' requirements at the threshold level as stated in the NPOESS IORD-1, providing more capability and benefit than the current programs. The increase in operational benefits to be obtained from the improved NPOESS system are significant, with different benefits accruing to different users. Of benefit to all users is the production of more timely, accurate, and reliable data. NPOESS will support the operational needs of the civilian, meteorological, oceanographic, environmental, climatic, and space environmental remote-sensing programs, and will provide global military environmental support, including geophysical and space support. In addition, NPOESS data will be available to over 120 different nations around the world in support of their forecasting capabilities. Weather is considered in every facet of military force planning, deployment and employment, and system design and evaluation. Despite the technological sophistication of today's weapons and support systems, most are impacted directly or indirectly by weather and environment. To achieve maximum advantage for our forces, weather information from NPOESS that is more accurate, or timely, more encompassing, and yet tailored to the specific needs of the commander, system operators, and planners must be received. For the warfighter, this translates into reduced casualties, reduced munitions expended to conquer a specific objective, fewer sorties aborted, more efficient selection and use or performance of weapon systems which are weather sensitive, and more reliable long-range planning. By meeting the IORD-1 threshold requirements, the NPOESS system will provide data which will improve forecasting, thus minimizing the consequences associated with use of the lower quality data available from today's systems.

Military benefits can be quantitatively measured in terms of the expended munitions and lives lost. The analysis behind the Cost, Operational Benefit, and Requirements Analysis (COBRA '97) showed that there was roughly a three to one improvement in the effectiveness of those military operations studied based solely on the improved environmental information provided by NPOESS as compared to today's capability. For example, it would take only one third the number of Dual Purpose Improved Conventional Munitions (dumb bombs) to achieve a given expected fractional target damage when NPOESS environmental data, vice data available today, is used in the firing solution. Similarly, the assumed radar detection range for an EXOCET-class missile would increase from 15 nautical miles (nm) to over 60 nm. (See Table 1 for other comparisons.)

NPOESS will also be used by the National Weather Service to improve 3-5 day weather forecasts. It will assist military and civilian airplanes in plotting the safest, fastest and most fuel efficient routes, direct ocean and Great Lakes shipping away from ice and bad weather, thereby increasing fuel efficiency, advance the study of climate change, and assist farmers, builders, utilities and other businesses affected by the weather. The search and rescue satellite payload on NPOESS will relay distress and geolocation signals from land travelers, as well as from ships and aircraft to search and rescue authorities. NPOESS data will be used by both DoD and the DOC/National Oceanic and Atmospheric Administration (NOAA) to generate global maps of snow cover which have impacts on agriculture (*e.g.*, water storage levels) and river forecasts (*e.g.*, flood forecasts). Over the years, thousands of human lives and billions of dollars are lost in natural disasters. The Federal Emergency Management Agency (FEMA) and the Army Corps of Engineers need forecasts with improved accuracy to reduce economic and life/safety impacts of floods, droughts, severe storms, and other weather-related hazards. The Tropical Prediction Center uses these data to provide storm-tracking, issue warning and alerts, resulting in saved lives, property, and dollars. NPOESS will contribute to an improved archival record of the land, ocean, atmospheric, and space environment, which will permit improved climate and teleconnection forecasts in the future. The archival record will enable us to better understand the processes which control our environment, to better understand the impacts of human activity, and thus to improve long-range prediction.

The Integrated Program Office (IPO) has undertaken a series of steps to quantify the civil benefits which can be anticipated from NPOESS. These include a COBRA ’98 activity directed toward civil benefits and the ongoing Observing System Simulation Experiments (OSSE) designed to evaluate the specific benefits from specific sensors and combinations. The COBRA ’98 Report includes work to date in tracing the product improvements which will result from NPOESS sensors and the economic and social applications which will benefit from improved information products. Over 80 application classes are identified which benefit from the NPOESS Environmental Data Records (EDRs) or products.

Civilian costs (savings) can be quantified in terms ranging from minor inconveniences / expenses incurred by millions of individuals, to major expenditures associated with severe storms, crop damage, airline transportation, and energy production which can be avoided due to more precise forecasts. In either case, better forecasts attributable to NPOESS enable the “user” to make more timely and informed decisions, and these decisions are reflected directly in cost savings. In the COBRA ’98 report, quantitative estimates for specific examples of four application classes indicate that economic benefits traceable to NPOESS will be in the range of millions to tens of millions of dollars per year. Other application classes are judged to be equal or smaller. Since the four cases studied total about $60M per year, and since there are over 80 applications which will benefit from NPOESS products, it is reasonable to project that direct economic benefit from NPOESS will be at least $100M per year.

Table of Contents

The following referenced documents are available upon request from the IPO:

a) Reconciliation of NOAA O,P,Q,R and DMSP Block 6 Life Cycle Cost Estimates

b) Life Cycle Cost Baseline for National Oceanic and Atmospheric Administration (NOAA) Follow-On (O,P,Q,R) Polar-orbiting Operational Environmental Satellites

c) Final Phase 0 Cost and Operational Benefits Requirements Analysis Report (COBRA)

d) COBRA '97 Update Executive Summary

e) COBRA '98 Update: Civilian Benefits Report

Polar Convergence

Operational Benefits and Cost Savings

1. Introduction

Background

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) resulted from White House and Congressional interest in converging the Department of Defense (DoD) and Department of Commerce (DOC) meteorological satellite systems into a more cost effective and higher performance integrated system than those in use today. The original goals were cost and efficiency driven (*e.g.*, to save at least $1.3B over planned follow-on systems per the National Performance Review[2] (NPR) guidance) while retaining the performance objectives of the requirements documents of the follow-on Defense Meteorological Satellite Program (DMSP Block 6) and the Polar-orbiting Operational Environmental Satellite (POES O,P,Q,R) program.[3] NPOESS is designed to maximize user satisfaction in terms of these requirements as currently documented in the NPOESS Integrated Operational Requirements Document (IORD-1)[5].

Congressional Language[1]

During their review of the FY 98 Budget, the House Appropriations Subcommittee for Commerce, Justice, State, the Judiciary, and Related Agencies stated that there were still some issues associated with the NPOESS program which needed to be addressed. The Conference Committee reiterated the Subcommittee's concerns and directed NOAA to follow the direction in the House Report regarding this matter[6].

The issues included in the House Report (105-207) are addressed below.

2. Current Program Funding Profile

"The Committee expects the Secretary of Commerce, not later than February 2, 1998, to submit a report on the current program --- funding profile ---."

"The Committee --- is concerned about the --- disproportional funding requests in the Departments of Commerce and Defense as included in the fiscal year 1998 budget submission."

[6] Department of Commerce Appropriation House Conference Report 105-405

Response: **[This response has been deleted since it contained Government Cost Information which may no longer be representative of the current NPOESS program.]**

The current NPOESS funding profile is shown in Figure 1 (NPOESS Savings) on the "Total NPOESS" line. Discussions were held among the NPOESS Integrated Program Office (IPO), DOC and DoD officials, and DOC and DoD Office of Management and Budget (OMB) examiners throughout 1997. By stretching out the program and eliminating some enhancements to the current DMSP and POES spacecraft, NPOESS was able to reach a compromise agreement on November 3, 1997, which satisfied the objectives of all participants. All organizations are now in agreement on the content, schedule, and budget for the NPOESS Optimized Convergence System (OCS). The NPOESS costs shown in Figure 1 for FY 99 and beyond reflect this agreement.

3. Current Program Plan

" --- submit a report on the current program plan --- "

"The Committee --- is concerned about the implications of --- proposed early availability of satellites ---."

Response: The statistical analysis of the NPOESS need dates to maintain the polar weather satellite constellations continues to indicate a 50%-likelihood need date for the first NPOESS satellite in early 2007 to back up either DMSP-20 and/or POES-N'. However, as part of the above OMB budget agreement and reflecting the revised schedule for NOAA-N-prime, the availability date for the first NPOESS satellite has moved out 6 months from January 2007 to July 2007, with a probable launch date of June 2008. Furthermore, two additional satellites will be needed by late 2010 to maintain the necessary operational availability of the weather satellite constellation. The Departments (DoD & DOC) firmly believe that uninterrupted maintenance of an operational weather satellite constellation, as well as efficient production rates, mandates that the NPOESS satellites be built, delivered, and available for launch on the agreed-to schedule. The IPO will continue to monitor the health and status of the current and future DMSP and POES on-orbit assets and suggest adjustments to the NPOESS need/availability dates as the situation warrants. The integrated, overall acquisition strategy is shown in Figure 2. The current program plan is reflected in Figures 3 and 4.

Figure 1. **NPOESS Savings Compared to Pre-Convergence Budgets**

FY 1995 to FY 2018 (Dollars in Millions)

[Figure 1 has been deleted since it contained Government Cost Information which may no longer be representative of the current NPOESS program.]

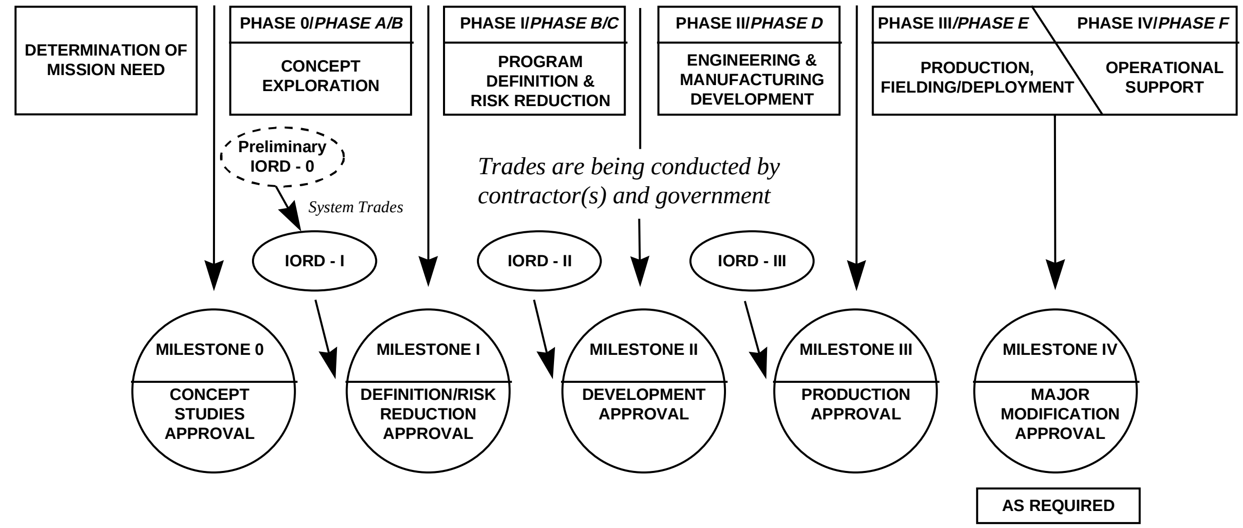

Figure 2: DoD / NOAA-NASA Acquisition Terminology Crosswalk

Near-Term Plans (FY 98 - FY 01)

NPOESS near-term acquisition activities are shown in Figure 3. The guiding tenets for NPOESS Optimized Convergence System (OCS) include accomplishing substantial net risk reduction[7] with a focus on payload development, user satisfaction, deferring major system decisions as long as reasonable, and protecting maximum flexibility for the Government to ensure the best overall system design. To these ends, the program anticipates development and risk reduction flights of selected payload sensors while deferring individual sensor selections among competing international, NASA, military, and industry alternatives, in order to assess and determine the optimum technical performance potential of each candidate sensor. In addition, the selection of the overall system prime contractor is being deferred to minimize up-front system level costs, during sensor complement design and selection, and to delay the commitment to full system acquisition until the third quarter of FY 01. It is likely that following the three-year payload development and risk reduction period, NPOESS will incorporate two payloads provided by the Europeans, three to five payloads from existing NASA EOS or New Millennium developments, and three to five payloads from our competitive sensor developments. It is expected that the prime contractor selected for the full NPOESS system will assume Total System Performance Responsibility (TSPR) for all of these payloads.

[7] Some additional risks will be incurred on POES and DMSP satellites modified for NPOESS sensors.

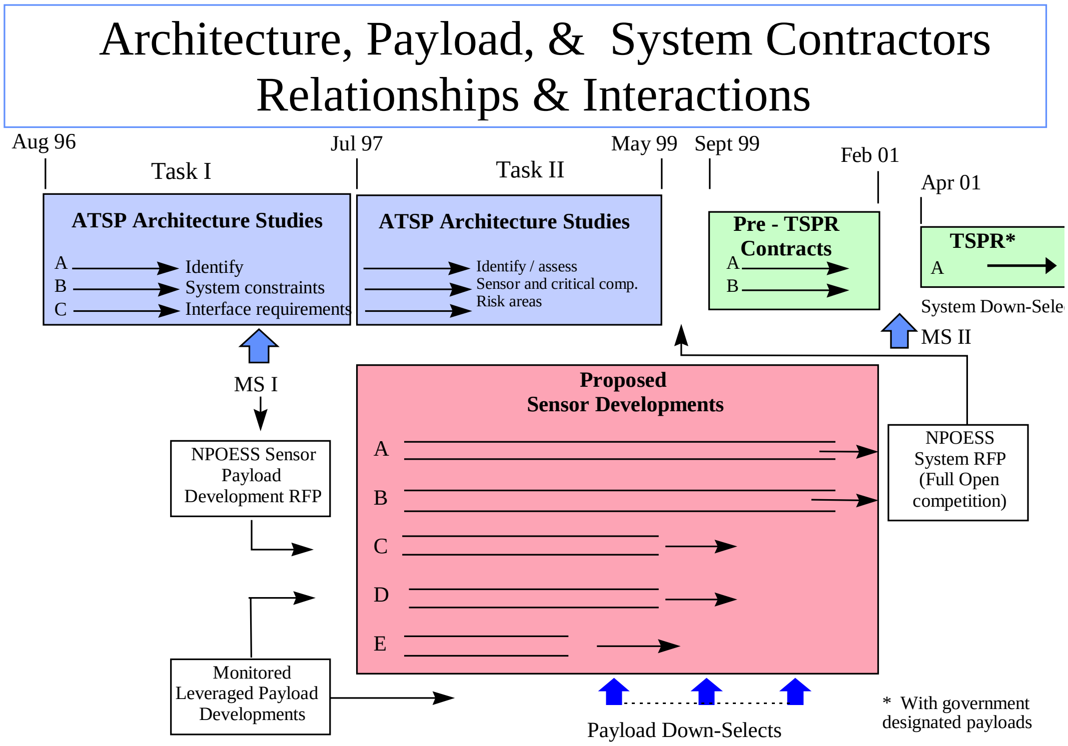

Figure 3: Near Term NPOESS Acquisition Activities

Advanced Technology Support Program (ATSP) Effort

The purpose of the Advanced Technology Support Program (ATSP) effort is to maintain three competitive system/architectural designs during the architecture definition and sensor risk-reduction phase of the NPOESS program. The contractors (Lockheed Martin, Hughes Electronics Co., and TRW) will perform system impact analyses and interface definition to recommend constraints to be used in the acquisition of various sensor payloads and perform the preliminary system engineering to integrate the sensor payloads with the space, launch, Command, Control and Communications (C3) and Integrated Data Processor (IDP) segments.

NPOESS Payload and Algorithm Development Effort

Many existing environmental and operational sensors are of early 1970's vintage technology. Furthermore, the design lifetimes of these sensors are approximately half the needed lifetime required to meet NPOESS requirements. The NPOESS IPO identified five sensor capabilities that warrant early development efforts to mitigate potential high-risk components early in the development process. They are: (1) Visible/Infrared Imager Radiometer Suite (VIIRS), (2) Conical Microwave Imager Sounder (CMIS), (3) Cross-track Infrared Sensor (CrIS), (4) Ozone Mapping and Profiler Suite (OMPS), and (5) Global Positioning System Occultation Sensor (GPSOS). Six contracts, covering nine separate development efforts, have been awarded for the development of these five sensors and associated algorithms through Preliminary Design Review (PDR). Initially the contractors will study the requirements, identify technical risk and risk mitigation, determine the best approach to satisfy the requirements, and develop a preliminary instrument/algorithm design. After PDR, one contractor will be “down-selected” for each instrument to carry their design into Engineering and Manufacturing Development and Production/Fielding/Deployment and Operations and Support.

Leveraged Payloads

A number of sensors planned for the NPOESS series will either be copies or close derivatives of the sensors that are being developed by other agencies or international partners. These programs will be monitored to ensure compatibility with NPOESS requirements. Thus competitive industry risk reduction/development contracts for these sensors are not part of the NPOESS acquisition strategy. Candidate leveraged payloads include: the radar altimeter on the NASA/French TOPEX/Jason series or the Navy’s Geosat/Geosat Follow-On series; NASA’s Clouds and the Earth’s Radiant Energy System (CERES); NASA’s Active Cavity Radiometer Irradiance Monitor (ACRIM); the U.S., French, and Canadian governments’ Search and Rescue System (SARSAT); and the French Data Collection System (DCS).

Program Definition and Risk Reduction (Pre-TSPR)

Multiple system level development contracts will be awarded for the NPOESS Program Definition and Risk Reduction efforts in the fourth quarter of FY 99, with an anticipated “down-selection” to the single system contractor following Milestone II in the third quarter of FY 01. During this period, each system-level contractor will generate an integrated system design that accommodates the Government designated sensor payloads and algorithms selected from the separate competitive development of advanced technology sensors and other U.S. Government sponsored or international payload development efforts.

Total System Performance Responsibility (TSPR)

At the completion of the Pre-TSPR system definition effort, and prior to Milestone II, the Government will release a “Call For Improvement” proposal which specifies the final payload selection and system parameters, thus allowing the competing Pre-TSPR contractors to update their proposed NPOESS system definition and life-cycle cost estimate and provide a final proposal. The contractors will be required to define a system concept which is both consistent with the assumption of Total System Performance Responsibility (TSPR), and is sufficiently flexible to accommodate the designated payload designs. “Down-select” and award of the TSPR contract is anticipated in the third quarter of FY 01 (after Milestone II), with the Preliminary Design Review (PDR) and Critical Design Review (CDR) following in the third quarter of FY 02 and the third quarter of FY 03, respectively, as shown in Figure 4.

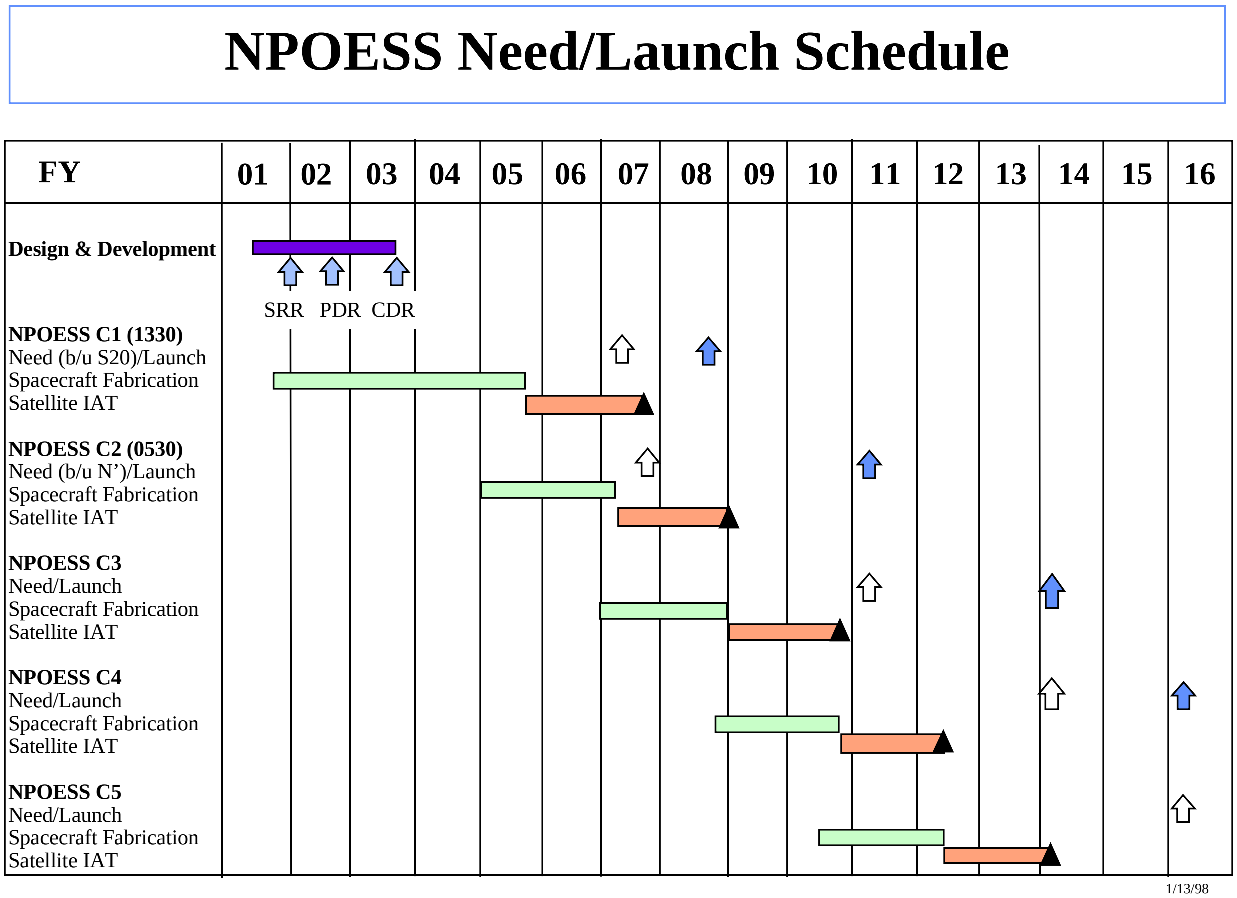

Figure 4
NPOESS Satellite Need Dates (open arrows), Probable Launch Dates (shaded arrows), and Availability Dates (black triangles)

<u>Long-Term Plans (FY 01 - FY 18)</u>

The NPOESS satellite need dates, availability dates, and probable launch dates are shown in Figure 4. The availability date for NPOESS C-1 was moved out from the original need date of December 2004, first to January 2007 with the original OCS plan, and then to July 2007 with the OMB compromise program. In total, these two changes in the NPOESS program plan provided substantial savings (> $500 million) and balanced the DOC and DoD contributions by year. Initially, the NPOESS IPO worked with the DMSP and POES programs, and the users, to arrive at a more efficient way of deploying the current DMSP and POES satellites. This was key to the development of the NPOESS Optimized Convergence System. NOAA agreed to move NOAA-M from a mid-morning orbit to an afternoon orbit and accepted the short-term risk of a gap in coverage for the morning orbit (which is a backup orbit for NOAA's mission) until the launch of the European Meteorological Satellite (EUMETSAT) organization's Meteorological Operational (METOP-1) satellite. The movement of NOAA-M to the afternoon enabled NOAA to delay the planned launch of N' until January 2007. For NPOESS Optimized Convergence, this enabled a

25-month slip in the delivery date of NPOESS C-1 from December 2004, to January 2007. This in turn translated into a 1-year slip to sensor development start, and allowed the deferral of Space, C^3, and Integrated Data Processing System (IDPS) definition and funding commitments by more than 4 years to September 2000.

The second schedule adjustment occurred as a result of the recent budget agreement reached with OMB during the formulation of the President's FY99 budget. The IPO has restructured the NPOESS program and moved the availability of NPOESS C-1 to July 2007. Again, the risk of being without an on-orbit asset continues to increase.

The current satellite production and launch schedule is also shown in Figure 4. Spacecraft design and development will begin in FY 01, with the System Requirements Review (SRR) and Preliminary Design Review (PDR) occurring as shown, and the Critical Design Review (CDR) being completed in FY 03. The spacecraft fabrication and satellite integration and acceptance test (IAT) schedules are shown on the shaded bars. The small black triangle at the end of the IAT line is the satellite delivery or "availability" date. The clear arrows show the anticipated need dates for the NPOESS satellites to back up the launch of the satellites they are intended to replace.[8] The shaded arrows show the 50 percent probability of launch dates. As can be seen, the estimated median need date for the first NPOESS satellite (C-1) to back up the last DMSP launch (S-20) is March 2007. However, since C-1 will not be available until July 2007, there is a risk that there could be a four-month gap in meeting DoD's needs in the event of a DMSP S-20 launch or early on-orbit failure. If S-20 is successful, C-1 may not be needed until July 2007 to back up the launch of POES-N'. In the event of an N' failure, without an N' back-up there would be no polar satellite coverage in the 1:30 P.M. time slot, which is the primary NOAA slot for collecting environmental and climatological observations and issuing reports. If both DMSP S-20 and POES-N' launches are successful, C-1 must still be reconfigured within 1 year to replenish the early morning orbit of DMSP S-19. Furthermore, two additional spacecraft (C-2 and C-3) are needed by late 2010 to maintain operational availability, and production realities dictate that production of these vehicles start in 2004 and 2007, respectively.

For the above reasons, the Departments believe that maintenance of an operational weather satellite constellation mandates that the NPOESS satellites be built, delivered, and available for launch on the agreed-to schedule shown in Figure 4.

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[8] Anticipated need dates are determined by the probability distribution of replacement, based on the expected life of current assets. If current spacecraft exceed the estimated design life, the need date is shifted toward the future.

4. NPOESS Cost Savings

"The Committee is concerned that the current program plan may not allow the original cost savings from convergence of $1,300,000,000 to be achieved."

"--- submit a report on the --- cost savings to be achieved from convergence."

Response: To ensure that the stated cost savings can be achieved from convergence, the IPO compared its own cost figures to several independent cost analyses as described below. The independent and IPO estimates were in close agreement. Based on these estimates, the IPO is confident that the NPOESS program will not only meet the $1.3B cost savings goal of the NPR, but will substantially exceed it.

[This paragraph has been deleted since it contained Government Cost Information which may no longer be representative of the current NPOESS program.]

Figure 5a: Cost Trend for NPOESS: Life Cycle Cost

Figure 5b: NPOESS Cost Estimate History

[Figures 5a, 5b, and the associated text have been deleted since they contained Government Cost Information which may no longer be representative of the current NPOESS program.]

<u>The NPOESS Cost trend is down</u>

5. Requirement Origin and Prioritization

"The committee believes that it is imperative that both Departments carefully review and prioritize NPOESS requirements."

Response: The Departments have prioritized their requirements by virtue of the process used to develop IORD-1 which has been validated by NASA, NOAA, and DoD. Beginning with 100 plus Environmental Data Records (EDRs), the process ended with 61 EDRs baselined and 9 additional EDRs identified as Pre-Planned Product Improvement (P^3I) requirements. It should be noted that only 8 of the 61 EDRs provide a functionality which is not available at some level on the current DMSP and POES missions. Also, nearly all of these were included in the requirements for DMSP Block 6 or POES O,P,Q,R follow-on programs.

The complexity of the NPOESS Instrument/EDR/Product interaction is shown in Figure 6, which, when read from right to left, maps the NPOESS instruments to their associated EDRs, measurement areas, and missions. Multiple sensors interact to provide data for multiple EDRs.

Requirements Development

Prior to convergence, the DoD, NOAA, and NASA user communities had developed Operational Requirements Documents for their follow-on polar environmental satellite systems. The satellite program offices (DoD's DMSP, NOAA's POES, and NASA's EOS) then conducted a number of architecture studies to determine the most cost-effective architecture for their individual programs. In October 1992, NOAA and NASA began working together to explore options for possible integration of the POES and Earth Observing System - PM (EOS-PM) programs. In February 1993, DoD and NOAA began a separate effort to identify opportunities for integration of the DMSP and POES programs.

At the request of the U.S. Congress (and as later directed by Vice President Gore's National Performance Review), the collaborative efforts previously initiated between NOAA and DoD, and NOAA and NASA were brought together in June 1993. Under the auspices of the Administration's Office of Science and Technology Policy (OSTP), DoD, NOAA, and NASA began a cooperative study effort to identify realistic opportunities for additional cost savings resulting from integration of all, or parts, of these agencies' three polar-orbiting environmental satellite systems. Senior oversight of the study was provided by a Triagency Steering Committee (TSC) consisting of senior representatives from DOC/NOAA (Chief Scientist), NASA (Deputy Associate Administrator for Earth Science), and DoD (Director, Strategic and Space Systems).

Requirement assessments continued throughout NPOESS Phase 0 under the direction of the TSC. The Joint Agency Requirements Group (JARG) was formed in June 1994. The JARG was responsible for developing the NPOESS Integrated Operational Requirements Document (IORD) and consisted of members representing the HQ Air Force Space Command (AFSPC), the Office of the Oceanographer of the Navy (CNO/N096), the Air Force Directorate of Weather (USAF/XOW), NOAA/National Environmental Satellite, Data, and Information Service (NESDIS), the NASA Goddard Space Flight Center (GSFC), the NOAA National Weather Service (NWS), the NOAA Office of Oceanic and Atmospheric Research (OAR), the NOAA National Ocean Service (NOS), the Office of Global Programs (OGP), and the Army's Deputy Chief of Staff for Intelligence, Intelligence Policy Directorate/Battlespace Operations & Surveillance Division. By January 1995, the JARG had trimmed the requirements set from over 100 Environmental Data Records (EDRs) to 70 EDRs with established "objective" performance levels, eliminating those EDRs which were too costly or technically unachievable and merging others. These objectives were documented in an Integrated Operational Requirements Document (IORD-0)[9].

In January 1995, the IPO selected two contractors (Lockheed and Martin Marietta) to conduct Phase 0 studies. As a part of the study, the contractors developed "knee-in-the-curve" sensitivity analyses for each of the EDRs in order to trade requirement thresholds versus cost. At the completion of the Phase 0 studies in August 1995, the contractors had recommended achievable, cost-effective thresholds for each of the EDRs. Examples of these cost/performance sensitivity analyses are shown in Figure 7. In the E/O Imager example, the 0.8 km resolution requirement falls on the flat portion of the curve, but not at the knee (approximately 0.4 km). In this case, the IPO elected not to incur the additional cost to get to the 0.4 km resolution since there was no requirement to do so. In the IR Sounder example, the 15 km horizontal resolution requirement falls right at the knee of the curve.

Using the results of the Phase 0 studies, coupled with the expertise of the scientists and engineers of the three agencies, the IPO initiated a further systematic review of all of IORD-0 requirements in conjunction with the users. The flow of these CAIV activities is depicted in Figure 8. Guided by the JARG during a series of iterative sessions (review/discussion/redirection), the IPO explored 61 Space Segment configurations and 8 different Command, Control and Communications / Interface Data Processor Segments (IDPS) configurations. These were combined into 25 different potential NPOESS architectures or architecture variants. The JARG used the feedback from the IPO to refine the requirements in IORD-0 and produced a draft IORD-1 in November 1995. The draft IORD-1 was released for agency review by the NPOESS Senior Users Advisory Group (SUAG) in December 1995. IORD-1 contained 61 EDRs specified at both the "Threshold" and "Objective" levels. In addition, 9 EDRs which were technically difficult to achieve, or cost prohibitive, were prioritized and designated as Pre-Planned Product Improvements (P^3I).

The 61 EDRs are shown in Figure 6. The required NPOESS measurement types have not changed significantly from the DMSP-5D3 and POES-N/N' requirements. Only 8 of the 61 EDRs are "new" and these are all traceable to either the Block 6 Operational Requirements Document or the NOAA Strategic Plan. Of the 61 EDRs, 38 are common to both DoD and

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[9] Integrated Operational Requirements Document (IORD-0) - For Preliminary Phase 0 Concept Studies, 16 Dec 1994.

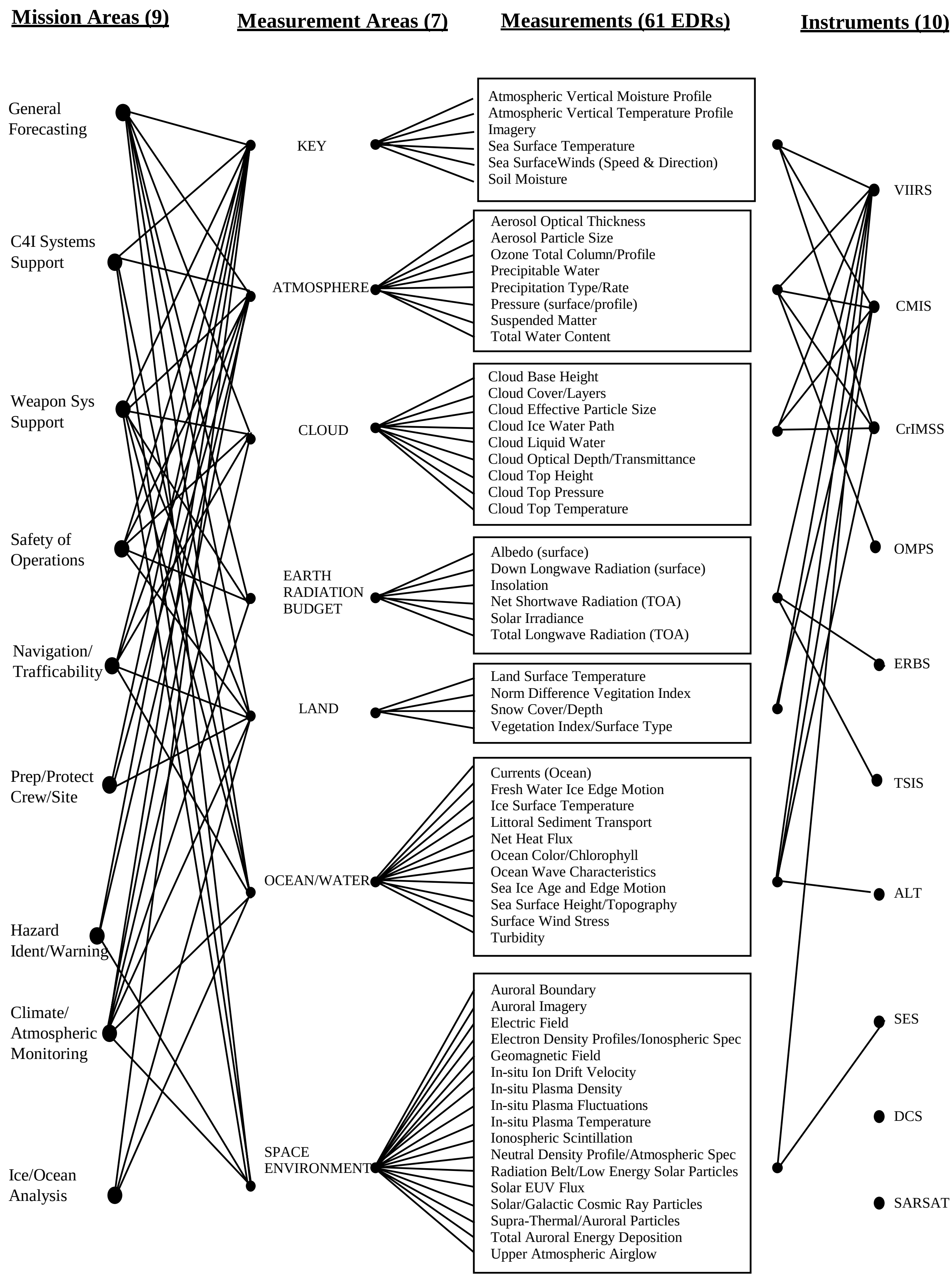
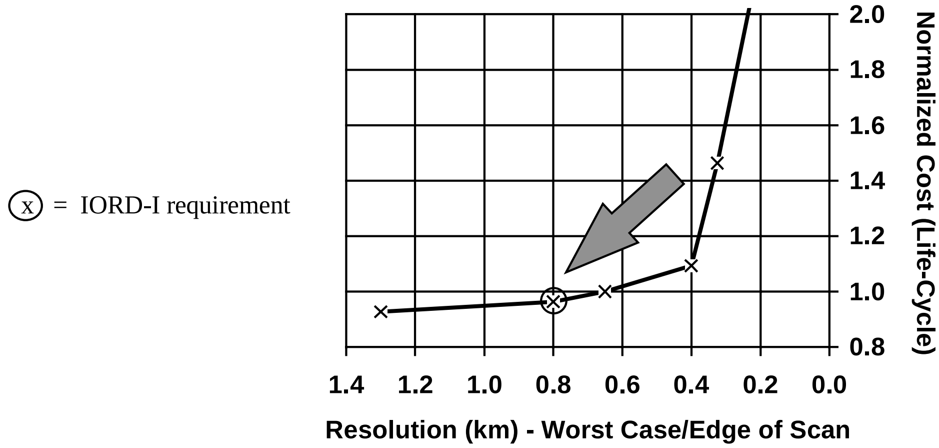
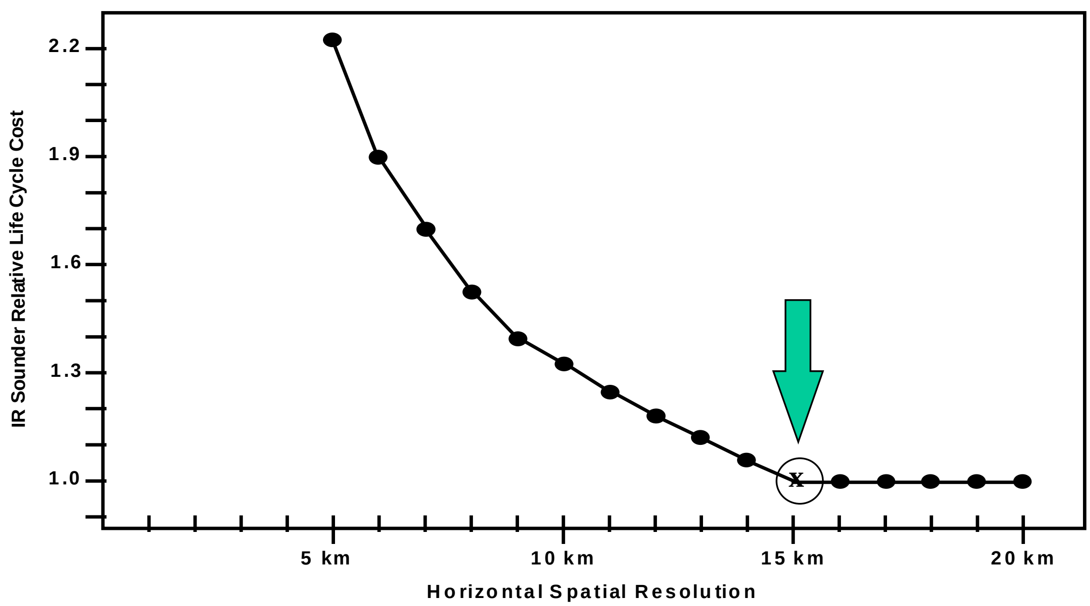


Figure 6. NPOESS Missions / Measurements / EDRs Map to Instruments



Cost versus Resolution for E/O Imager/Radiometer



Cost versus Horizontal Resolution for IR Sounder

Figure 7: Examples of Cost/Performance Curves

DOC. The remaining 23 EDRs are called "unique" as their attributes are primarily driven by one of the two agencies. These "unique" EDRs are evenly divided between DoD (11) and DOC (12). However, both agencies plan to routinely use data from all of the "unique" EDRs, as well as the common EDRs in their daily operations.

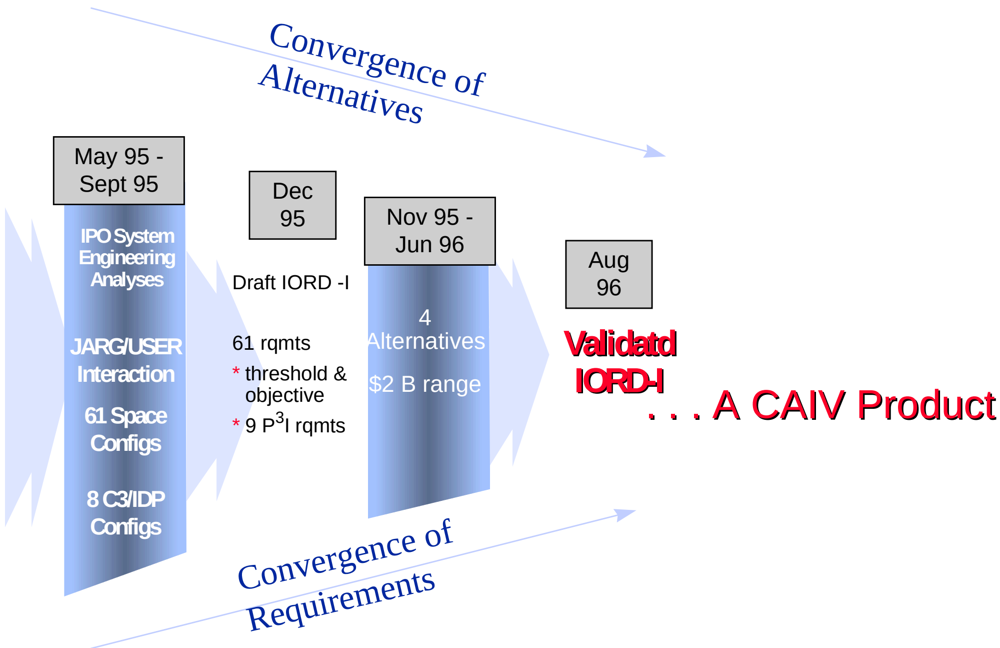


Figure 8: Phase 0 CAIV Activities

6. Planned Upgrades

> *"The Committee --- is concerned about the implications of proposed significant upgrades for instrumentation ---."*

Response: The NPOESS instruments are similar in function to the ones currently flown on POES and DMSP, and the upgrades to these instruments are much more evolutionary in nature, than revolutionary. Combining functions of instruments, which is mandated by the convergence of two platforms, coupled with the need to replace obsolete components/technology will, of necessity, create a redesigned instrument which is more capable. Improved performance flows from modern technology and merged designs, rather than improved performance driving complex designs. While the physical upgrades are not significant in terms of technology and cost, the operational benefits received from these improvements are comparatively large. It would be imprudent, and a disservice to the users, not to take advantage of the benefits of new technology to the fullest extent possible, as NPOESS will be flying for the next 20 years.

Use of the term "significant upgrades" is misleading. The complement of instruments planned for the NPOESS payload are similar to the types of instruments that are currently being flown on DMSP and POES, or planned for their follow-on missions - *e.g.* imagers, visible, infrared, and microwave sounders, space environment and earth radiation budget monitors, etc. The evolving needs of both the military and civil sector have resulted in evolutionary requirements for improved environmental data quality as reflected in IORD-1. These requirements have, in turn, resulted in evolutionary, not revolutionary, upgrades for NPOESS instruments. The upgrades for NPOESS are following the trend of upgrades over the past 30 years. In most cases, the enhanced requirements are not driving the complexity of the instruments.

The complexity of these instruments, and perceived jump in performance, arises from the fact that, in order to fit on the spacecraft, they are being redesigned to:

a) merge the capabilities of similar instruments on the two (DMSP & POES) platforms whose primary functions were inherently different.

   For example, the Advanced Very High Resolution Radiometer (AVHRR) on POES is an imager with the emphasis on radiometric accuracy, while the Operational Line Scan (OLS) instrument on DMSP is an imager with the emphasis on high resolution/definition visible pictures. When these capabilities are combined into a single multifunction instrument to meet both DoD and DOC requirements on one platform, the end product is a new instrument (the Visible Infrared Imaging Radiometer Suite (VIIRS)) which has more channels, each with higher resolution and radiometric accuracy, than the existing instruments.

b) replace obsolete components,

   These changes make the instruments much more capable in many areas merely because we are replacing 1970s and 80's technology with year 2000 technology. The functionality and capability of new technology, when combined with the reduction in size of components, are a significant advance. For instance, replacing standard tape recorders with multi-gigabyte solid state memories vastly increases the amount of data that can be stored, and therefore collected, on orbit. It would be almost impossible not to take advantage of the increased capability inherent in the new technology since the cost of a one-gigabyte magnetic tape recorder, if you could find one, would be significantly higher than an off-the-shelf multi-gigabyte solid state recorder.

c) extend their mean mission duration.

   To keep the cost of the NPOESS system down, it is necessary to design instruments and spacecraft which last longer. Therefore, it requires fewer spacecraft to maintain an operational capability which spans the mission lifetime from launch until 2018. In the process of redesigning the instruments, the better technology required for extended life also leads to improved performance. The same solid-state memory which increases storage capacity enhances system reliability by eliminating moving components.

The risk of the changes described above is manageable due to the IPO's aggressive risk-reduction program, whose goal is to demonstrate several of these new instruments on other platforms before integrating them all onto the NPOESS satellite.

7. Operational Benefits

"--- submit a report --- which details the operational benefits --- to be achieved from convergence."

Response: To date, three separate Cost, Operational Benefit, and Requirements Analyses (COBRA) have been performed by the IPO, each in accordance with DoD or DOC guidance. These are described below and are available upon request. In each case, the value added by the complement of NPOESS sensors, in terms of lives and property saved, timely decision making, cost avoidance, and general convenience to both the public and private sectors, has been shown to exceed the marginal costs of NPOESS over the cost of continuing today's capability.

<u>Cost and Operational Benefit Requirements Analysis (COBRA)</u>

Throughout the summer of 1995, discussions were held with the DoD Program Analysis and Evaluation (PA&E) group to determine what should be included in an NPOESS Cost, Operational Benefit, and Requirements Analysis. This effort resulted in the "Guidance for Phase 0 Cost, Operational Benefit, and Requirements Analysis (COBRA) for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Program," October 11, 1995. This guidance was coordinated with NOAA and NASA members of the Overarching Integrated Product Team (OIPT) and forwarded to the NPOESS System Program Director (SPD) by the Under Secretary of Defense (Acquisition and Technology) [USD (A&T)] on November 14, 1995. The specific COBRA guidance was to "…meet the objectives of achieving substantial cost savings through convergence while fulfilling the operational requirements of NOAA and DoD." Three target cost goals, each with respect to the combined projected Life Cycle Cost[5] of the follow-on DMSP Block 6 and POES O,P,Q,R programs,[3] were specified in the COBRA guidance:

- $ 2.0 B Life Cycle Cost savings (Alt 1);
- $ 1.3 B savings (Alt 2); and
- $ 0.0 savings (Alt 3A & Alt 3B)

Figure 9 shows the NPOESS CAIV trade space. The objective of the COBRA was to define systems that would satisfy as many of the IORD-1 requirements (system level and Environmental Data Records (EDRs)) as possible, at the threshold level, within the cost constraints stated in the above COBRA guidance:

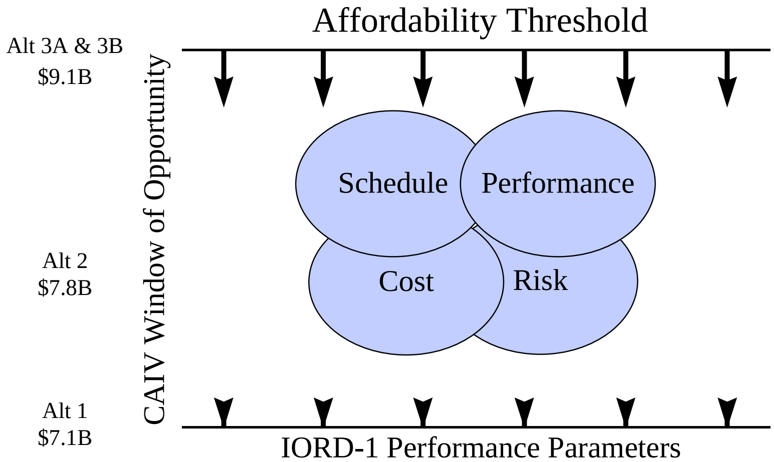


Figure 9: NPOESS COBRA Trade Space

Per the COBRA guidance and the Office of Science and Technology Policy Implementation Plan, definition of the alternatives was again a user-driven process. Thus, the technical aspects of the alternative definition (architectures) process was based on a series of summary-level, cost performance trade-off analyses. These analyses considered Phase 0 contractor information as well as all of the previous internal IPO and other Government studies. Eleven of the alternatives generated during the conduct of IPO system engineering trade-off analyses provided a starting point for defining the most effective cost-constrained alternatives for the COBRA. First, IPO defined an NPOESS architecture (Alternative 2) that satisfied the IORD-1 threshold level requirements (all system-level requirements and 61 of 70 EDRs, see Figure 6 for the listing of EDRs) within the specified cost constraint (*i.e.*, $1.3B LCC savings from the combined follow-on DMSP and POES program costs in then year dollars, as directed in the Vice President's NPR). The additional nine P^3I EDRs, although requirements in IORD-1, were not addressed by Alternative 2 because they were deemed inappropriate to implement at this time due to technical complexity, cost, or weight/volume accommodation constraints. Figure 6 highlights the complexity and interaction of the Alternative 2 instruments, EDRs, Measurement Areas, and Mission Areas. Alternative 2 became the "JARG/SUAG preferred" alternative.

Next, a subset of IORD-1 requirements were analyzed, guided by the JARG, to determine a minimum cost alternative to meet the most stringent cost target (*i.e.*, $2.0B LCC savings per COBRA guidance). This particular architecture (Alternative 1) met 50 of the 70 EDRs at the threshold level plus all system level requirements except survivability. The SUAG ultimately rejected this alternative as being "non-responsive" to IORD-1.

Finally, in order to satisfy as many EDRs as possible within the CAIV trade space, the remaining nine P^3I IORD-I requirements were analyzed to determine which EDRs could be "added" (to the 61 already satisfied by Alternative 2) within the final COBRA cost target (*i.e.*, $0.0 LLC savings). Two architectures were defined and presented as high-cost alternatives (Alternatives 3A and 3B). Alternatives 3A and 3B each addressed some, but not all, of the P^3I EDRs.

Appendix D of the Final Phase 0 COBRA Report[10] has details on each of the alternatives, including EDRs satisfied (or not).

The TSC and individual SUAG members were kept apprised of the COBRA process, progress, and results. On April 12, 1996, the draft COBRA results were briefed to an informal session of the DoD Overarching Integrated Product Team (OIPT), which included senior DoD officials, as well as NASA and NOAA representatives. With the exception of PA&E, the OIPT members supported IPO presentation and COBRA conclusion recommending Alternative 2. PA&E, however, while not taking exception to what was in the draft COBRA report, felt that another alternative which did not meet IORD thresholds should be evaluated as a lower cost alternative. This alternative was deemed unacceptable to the agencies involved. IORD-1 was approved by the DoD Joint Requirements Oversight Board on May 31, 1996 and the COBRA report was promulgated June 12, 1996. The operational benefits accruing to the NPOESS system are described in Appendix G of the COBRA report. These descriptions are primarily qualitative in nature, addressing the consequences of not receiving the information contained in specific EDRs. The Joint Agency Requirements Council[11] (JARC) formally approved the March 28, 1996 IORD-1 as the official NPOESS requirements document on August 7, 1996, thereby endorsing COBRA Alternative 2 as the “user preferred” alternative.

COBRA ’97 Update

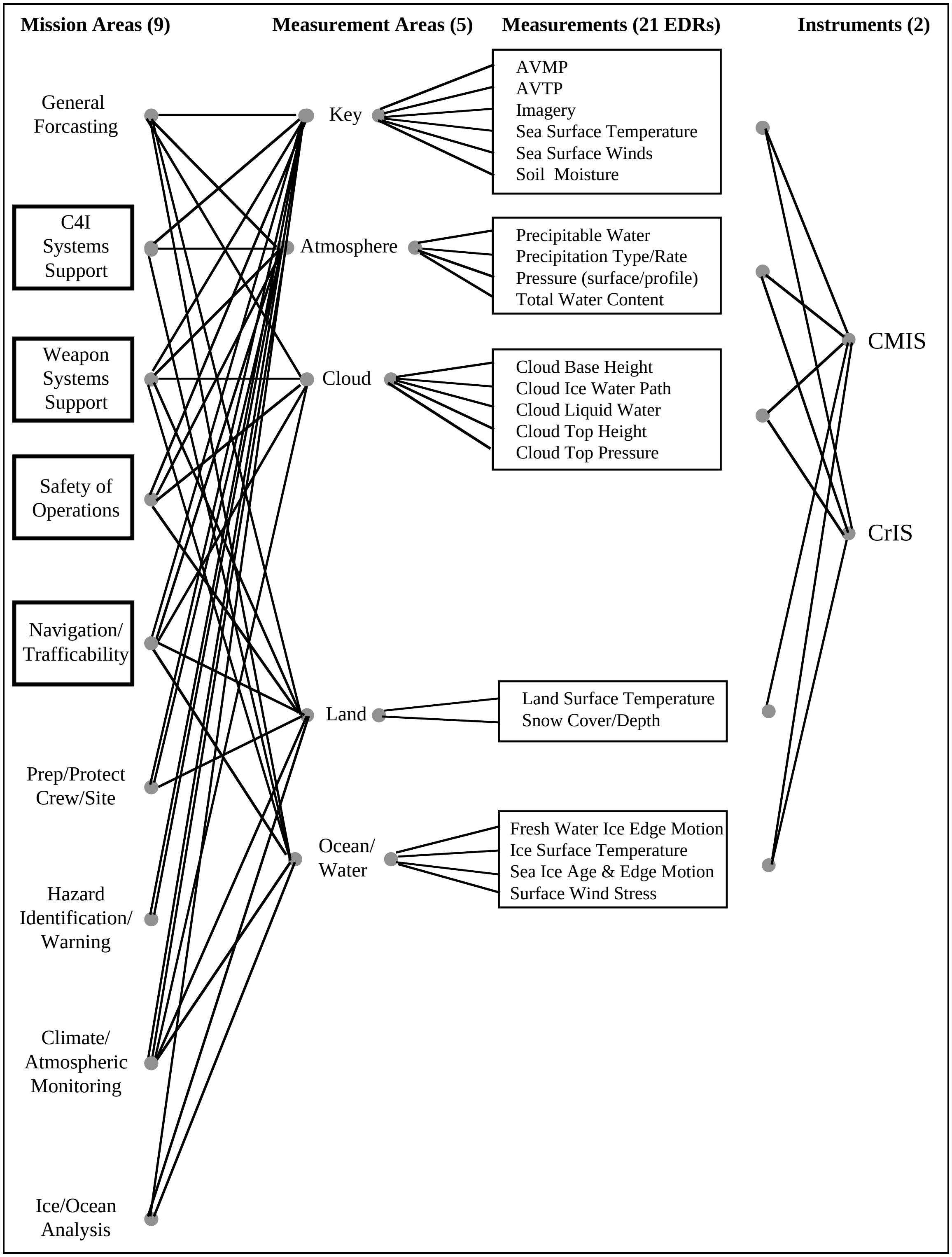
NPOESS CAIV activities did not cease with the advent of OCS. On August 20, 1996, PA&E briefed their recommended NPOESS alternative to the SUAG. The PA&E alternative for NPOESS (hereafter referred to as ALT A) would maintain weather satellite system capability at no better than the present (DMSP and POES) capability while minimizing investment costs. ALT A was identical to the OCS Alternative 2 with the following exceptions:

- the notional Conical Microwave Imager Suite (CMIS) was replaced by the Special Sensor Microwave Imager (SSM/I) and AMSU-B;
- the notional Cross-track Infrared Sounder (CrIS) was replaced by the HIRS-3;
- use of a smaller spacecraft eliminated reserved payload growth margin;
- the Enhanced Infrared Sounder was not developed or flown on NPOESS;
- the Global Positioning Satellite Occultation Sensor (GPSOS) was not developed in time to fly on DMSP or POES; and
- the Ozone Mapper/Profiler Suite (OMPS) was not developed and flown on NOAA N’ (ALT A uses an SBUV on N’).

10 Final Phase 0 Cost and Operational Benefits Requirements Analysis Report (COBRA), June 12, 1996.

11 JARC membership consists of the Vice Chairman of the Joint Chiefs of Staff for DoD, the Deputy Under Secretary of Commerce for Oceans and Atmosphere, and NASA’s Associate Administrator for Earth Science (formerly Mission to Planet Earth).

Figure 10: ALT A Sensor to Mission Mapping



ALT A did not achieve, at the threshold level, 21 of the 61 IORD EDRs which were fully satisfied by the NPOESS OCS (COBRA Alternative 2) architecture, including all 6 of the “Key” EDRs. Figure 10, when read from right to left, maps the affected instruments to their associated EDRs, measurement areas, and missions. As it turned out, ALT A was less expensive than the OCS architecture due to both the relaxation of requirement thresholds and a decrease of risk-reduction activities. ALT A was rejected by the SUAG as it did not meet over a third of EDR thresholds.

On September 6, 1996, the DoD Program Review Group (PRG) met to consider the NPOESS budget. The PRG recommended further Operational Benefit Analysis of both the NPOESS OCS and PA&E alternatives prior to Milestone I. In late September, PA&E presented their alternative to the Defense Review Board (DRB). The DRB issued Program Decision Memorandum II[12] (PDM II) directing a quantitative analysis of cost-requirement trade-offs, continuation of CAIV; inclusion of a cost and operational benefit analysis of the PA&E Alternative in the updated COBRA for Milestone I. In addition, the COBRA/CAIV results were to be briefed to the Milestone I EXCOM and to the Deputy Secretary of Defense, Deputy Secretary of Commerce, and NASA Administrator. NOAA and NASA EXCOM members were notified of this decision by memo from USD(A&T).

Working hand-in-hand with PA&E, the IPO developed and executed a plan to provide a quantitative assessment of the difference in military related operational benefits between the ALT A and NPOESS OCS architectures. This analysis showed that there were significant shortcomings with ALT A, not only in requirement satisfaction, but also in operational utility. These results are summarized in Table 1. The results of this analysis were published in the COBRA ’97 Update[13]. Based on this analysis, PA&E withdrew their ALT A and supported the original NPOESS OCS architecture at the March Milestone I EXCOM, stating that “There is no compelling reason not to continue with OCS”. The COBRA ’97 efforts were praised by the Director, PA&E and the Director, Operational Test and Evaluation, at the March 10, 1997, Defense Advisory Board Readiness Meeting.

[12] SECDEF Program Decision Memorandum, 9 October 1996.
[13] COBRA ’97 Update Executive Summary, March 17, 1997.

Strategic Area	Metric Explored	OCS Assessment	ALT A Assessment
	SUAG Assessment	Acceptable	Unacceptable
Fire Support	Normalized # of Munitions Predicted for EFD[1] =0.3: DPICM[2] SADARM[3]	 1 1	 3 2
Maneuver	Expected Forces Able to Traverse Grid[4]	100%	40%
Naval Operations	Assumed Radar Detection Range vs. EXOCET-class Missile [5]	59-74 nm[6]	15 nm
Mission Planning	Normalized NOWCAST Error Rate	1	2.7 (avg.)
Forecasts & Warnings		Acceptable	Significant Negative Impacts on Numerous Forecasts

1. EFD is Expected Fractional Damage
2. DPICM is the Dual Purpose Improved Conventional Munition
3. SADARM is Sense and Destroy Armor
4. One case only, one group of vehicles over one 140 x140 km grid with a single "dry" path
5. Assuming finer sampling interval allows you to see duct (OCS) and coarser sampling does not (ALT A).
6. Depending on scan elevation angle.

Table 1: Summary National Security Operational Benefit Analysis Results

COBRA '98 Update

The IPO has undertaken a series of steps to quantify the civil benefits which can be anticipated from NPOESS. These include a COBRA activity directed toward civil benefits and the ongoing Observing System Simulation Experiments (OSSE) designed to evaluate the specific benefits from specific sensors and combinations of sensors. Working closely with the National Weather Service (NWS) and the National Environmental Satellite, Data, and Information Service (NESDIS), the IPO conducted these analyses and documented them in the COBRA '98 Update[14].

[14] COBRA '98 Update, Civilian Benefits Report, February 1998.

Traditionally, the civil environmental satellite community has not attempted to quantify benefits from sensor improvements, for several reasons.

- First, the qualitative improvements in forecasts and other information produced by these satellites have been well established in retrospect.
- The quality of forecasting improvements has resulted from the parallel improvements in sensors (remote and direct), computers, and models and algorithms.
- Improvements have been made in spaceborne sensors when enabled by technology and/or specified by the experts who use the data.
- Environmental information has always had a special place in U.S. technology, policy, and statutes, due to its generally accepted benefits to individuals and commerce. Thus, its wide dissemination is broadly held to be critically important to the general welfare. As a result, no consistent effort has been made to identify its uses, and no pricing exists to establish its "market" value.
- Finally, the analytical complexity of identifying the contribution of each remotely-sensed parameter under a wide variety of conditions and to a large number of potential applications, then placing a quantitative value on each contribution, has not been considered worthwhile.

The NPOESS IPO understands the importance of such analysis to justify program requirements.

The COBRA '98 report includes work-to-date in tracing the product improvements which will result from NPOESS sensors, and the economic and societal applications which will benefit from improved information products. NPOESS will produce 61 Environmental Data Record (EDR) types which trace their heritage to the POES and DMSP programs. New technologies demonstrated on these and other NOAA, DoD, and NASA programs will be incorporated, and will enable NPOESS to produce improved data quality. The EDRs contribute to hundreds of products used by the civil community. Over 80 application classes are identified which benefit from the NPOESS EDRs or products.

Civilian costs (savings) can be quantified in terms ranging from minor inconveniences/expenses incurred by millions of individuals, to major expenditures associated with severe storms, crop damage, airline transportation, and energy production which can be avoided due to more precise forecasts. In either case, better forecasts attributable to NPOESS enable the "user" to make more timely and informed decisions, and these decisions are reflected directly in cost savings. In the CORBA '98 report, quantitative estimates for specific examples of four application classes indicate that economic benefits traceable to NPOESS will be in the range of millions to tens of millions of dollars per year for many application classes.

Although not all approach this high benefit level, there are over 80 other identified application classes which will benefit from NPOESS products enhancements. Since the four cases studied total about $60M per year, it is not unreasonable to project that direct economic benefit from NPOESS will be at least $100M per year.

It will also contribute to direct societal benefits in improved watches and warnings, and better public weather forecasts. It will contribute to an improved archival record of the land, oceans, atmospheric, and space environments, which will permit improved climate and teleconnection forecasts in the future. The archival record will enable us to better understand the processes which control our environment, to better understand the impacts of human activity, and thus to improve long-range prediction.

From these analyses, it is evident that the exploitation of even a fraction of these applications will result in cost savings which more than offsets the additional cost for the improved capability of NPOESS.

NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS)

NPOESS
Cost, Operational Benefit, and Requirements Analysis (COBRA) 1998 Update:

Civil Benefits Report

Prepared for the

National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data, and Information Service (NESDIS)

by

The National Polar-orbiting Operational Environmental Satellite System
Integrated Program Office

February 2, 1998

Revised 17 February

Table of Contents

Executive Summary

The Integrated Program Office (IPO) has undertaken a series of steps to quantify the civil benefits which can be anticipated from the National Polar-orbiting Operational Environmental Satellite System (NPOESS). This report, concentrating on civil benefits, updates the Phase 0 NPOESS Cost, Operational Benefit, and Requirements Analysis (COBRA) studies, results of which were formally documented and delivered in June 1996, and the COBRA 1997 Update, delivered 17 March 1997, which emphasized specific benefits in the national security sector. Another step is the ongoing Observing System Simulation Experiments (OSSEs) which will further quantify the specific benefits from specific sensors and combinations.

Traditionally, the civil environmental satellite community has not attempted to quantify benefits from sensor improvements, for several reasons.

- The qualitative improvements in forecasts and other information produced by these satellites has been well established in retrospect.
- The quality of forecasting improvements has resulted from the parallel improvements in sensors (remote and direct), computers, and models and algorithms.
- Improvements have been made in spaceborne sensors when enabled by technology and specified by the experts who use the data.
- Environmental information has always had a special place in US technology, policy, and statutes, due to its generally accepted benefits to individuals and commerce. Thus, its wide dissemination is broadly held to be critically important to the general welfare. As a result, no consistent effort has been made to identify its uses, and no pricing exists to establish its "market" value.
- Finally, the analytical complexity of identifying the contribution of each remotely sensed parameter under a wide variety of conditions to a large number of potential applications, then placing a quantitative value on each contribution, has not been considered worthwhile.

We understand that under present budget constraints, the effort must be made.

This report includes work to date in tracing the product improvements which will result from NPOESS sensors (Section 2), and the economic and societal applications which will benefit from improved information products (Section 3). NPOESS will produce 61 environmental data record (EDR) types, which trace their heritage to the POES and DMSP precursor programs. New technologies demonstrated on these and other NOAA, DoD, and NASA programs will be incorporated, and will enable NPOESS to produce improved data quality. The EDRs contribute to hundreds of products used by the civil community. Over 80 application classes are identified[1] which benefit from NPOESS EDRs or products. This report provides quantitative case studies[2] for examples taken from very different application classes: specifically, aircraft routing, electric power generation, northwest orchards, and satellite-based land remote sensing. The studies

[1] Appendix C.

[2] A discussion of the estimation process, including general limitations and specific assumptions used, is found in Section 3.

suggest that economic benefits traceable to NPOESS will be in the range of millions to tens of millions of dollars per year for many application classes.

Although not all approach this high benefit level, there are over 80 other identified application classes which can benefit from NPOESS product enhancements. Since the four cases studied total about $60M per year, it is reasonable to project that direct economic benefit from NPOESS will be at least $100M per year. This economic value is consistent with an alternative estimate based on a 1% improvement in the overall value of weather forecasting to the nation.[3]

NPOESS will also contribute to direct societal benefits in improved watches and warnings, and better public weather forecasts. It will contribute to an improved archival record of the land, ocean, atmospheric, and space environments, which will permit improved climate and teleconnection[4] forecasts in the future. The archival record will enable us to better understand the processes which control our environment, to better understand the impacts of human activity on environment, and thus to improve long range prediction and policy making.

The incremental economic and societal benefits described in this report are in addition to the initial and recurring savings from developing and operating a converged polar satellite program, currently estimated to be $1.8 billion[5].

Finally, the economic benefits need to be considered in a comparative context. Over the period 2008-2018, the $100 million annual benefits cited above would amount to more than the total Program cost to develop, design, and fabricate *all* NPOESS instruments, or half as much again as the estimated savings from convergence.

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[3] Based on NIST study discussed in Section 4.
[4] Definitions are found on page F-2.
[5] IPO, *Report on Polar Convergence Operaitonal Benefits and Cost Savings*, 2 February 1998

1. Introduction

This report represents the preliminary results of a study into the socioeconomic benefits to be anticipated from the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The study was initiated by the Integrated Program Office, which manages NPOESS. The present study emphasizes benefits to the civil sector.

The IPO has undertaken a series of steps to provide a comprehensive and consistent understanding of the anticipated costs and benefits from evolving environmental satellite programs. The IPO began a significant observing system simulation experiment (OSSE) program with the National Oceanic and Atmospheric Administration (NOAA) to prepare a modeling tool which can, for the first time, enable quantitative prediction of information improvements from alternative sensor and processing approaches. The original COBRA study[6] and COBRA Update[7] described benefits to the national security sector, incorporating the results of specialized studies carried out by the Army and Air Force. In preparing the published COBRA studies, the IPO realized that the civil community has not had the experience with benefits analyses that DoD has been required to conduct, so that there is less quantitative evaluation of the relationship between its sensing capabilities and its user applications. In response, the IPO began an internal project with NOAA in 1997 to document the relationship.

This status report presents the results to date. The remainder of this section discusses the scope of operational benefits in the civil sector, the specific scope of the IPO-related operational benefits question, and the difficulties which are encountered in trying to identify and quantify benefits. Section 2 begins the analysis by tracing from sensors to information products. Section 3 completes the trace from information products to applications, from which benefits accrue. It includes some specific examples. Section 4 summarizes the results, relating specific results to the totality of societal and economic benefits. Supporting details are found in the appendices.

1.1 Defining Operational Benefits

In the defense community, “operational benefits” is the term most often used for a study of benefits to the operational mission of the reporting agency. Within NOAA, the analogous definition would apply narrowly to the agencies which operate satellites (National Environmental Satellite, Data and Information Service [NESDIS]) and prepare forecasts and similar products (National Weather Service [NWS] and National Centers for Environmental Prediction [NCEP], for example). A more appropriate term for use in the civil sector is “socioeconomic benefits”, since they may be either societal or economic.

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[6] IPO, *COBRA*, NOAA/IPO, June 1996.
[7] IPO, *COBRA 1997 Update: Executive Summary*, NOAA/IPO, 17 March 1997.

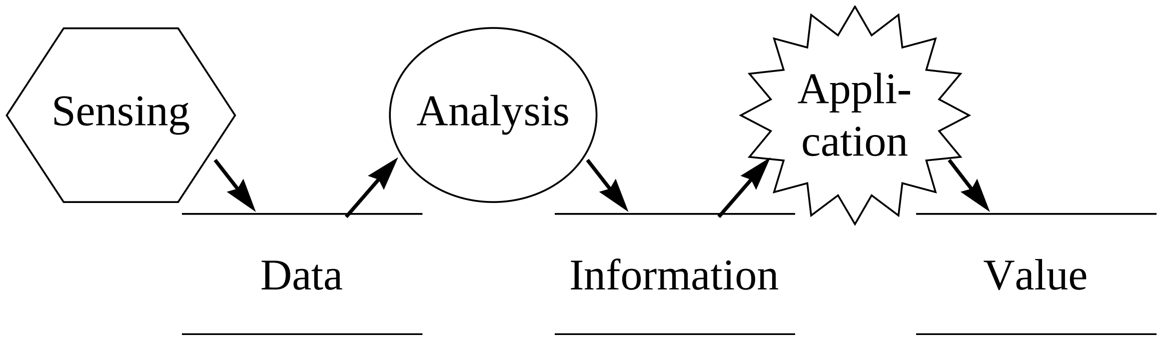

Figure 1-1. Essential flow relating sensing capabilities to socioeconomic benefit
At the conceptual level, the process examined in this report considers three processes and three products. Environmental sensors produce data sets which sample and represent certain limited environmental parameters. These are analyzed using models, algorithms, and retrospective comparisons to produce useful information about the current and future state of the environment. Users apply the information products to real decisions (activities) which depend on the environment, and on average receive some positive value with respect to the same decisions made without the information.

Economic benefits tend to be more easily monetized, and influence people directly or indirectly through factors such as the cost of living, productivity and income, and accumulation (or loss) of wealth. Examples of economic benefits are minimizing damage to property and lost production.

Societal[8] benefits may be more critical, when they involve storm watches and warnings, but are often difficult to monetize, such as reductions in unwarranted evacuations or travel disruptions. Other societal benefits are essentially impossible to quantify because they are at the same time subtle and pervasive: the improved understanding of environmental processes, higher confidence in the quality of forecasts, or knowing that the El Nino-Southern Oscillation (ENSO) phenomenon connects the equatorial Pacific with U.S. seasonal weather. The benefit may be not nearly so grandiose: knowing you can plan what to do on the weekend is an issue for most Americans 52 times per year. Notionally, if $0.001 is the average value to each person to provide better forecasts for that alone, the annual total value could be $13,000,000.

For the purpose of this study, the benefits need to be traced from the data provided by the satellite (Figure 1-1). NPOESS performance is specified in terms of Environmental Data Records (EDRs). There are at present 61 EDRs specified in the Integrated Operational Requirements Document (IORD)-I[9], and summarized in Appendix A. EDRs were established by a joint requirements review process among NASA, NOAA, and DoD. The EDRs specify the data products to be produced, not the instrument characteristics from which the EDRs are produced. From this point, the trace is performed in two steps: EDRs to weather products (discussed in detail in Chapter 2, schematized in Figure 1-2a);

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[8] Sometimes, "social benefits".
[9] IPO, *Integrated Operational Requirements Document - I (IORD-I)*, NOAA/IPO, March 1996.

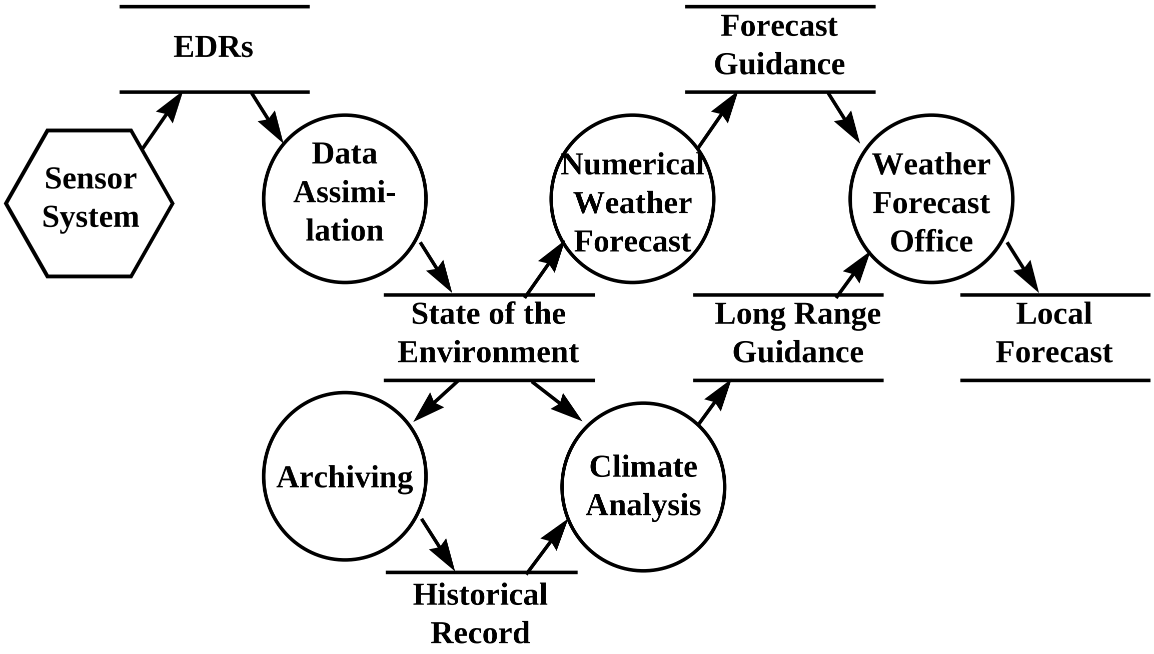

Figure 1-2a. Sensors to products: weather & climate example
NPOESS will support several specific instances of the process in Fig. 1-1, typified here by weather. Several sensors on NPOESS platforms produce data sets in the form of EDRs. These are collected and combined with complementary data sets in the first analytical process, data assimilation, to produce a synthetic "snapshot" of the environment, or synoptic analysis. The snapshot is archived to support climatic analysis for long-range guidance, and provided directly to atmospheric modeling algorithms which propagate the state of the environment forward, producing general forecasts of key atmospheric parameters. Climatic analyses and forecast guidance are combined with regional observations, familiarity, and skill to produce local and regional hydrometeorological forecasts. By the time synoptic analysis is complete, the original character of the data sets has been lost through extrapolation, resampling, and conversion to meaningful environmental parameters.

and weather products to benefits (Chapter 3, Figure 1-2b). Both steps are much more complicated than they appear at first. Although a few EDRs are useful for applications as produced, most environmental products are a blend of sources, both current and historical. The step from an environmental product to a socioeconomic benefit is usually mediated by a decision process which involves many factors in addition to the purely environmental factors.

Civil benefits also cover a range of direct to highly indirect applications. Direct applications include the immediate use of an environmental observation: the location of high phytoplankton concentrations, the extent of a volcanic eruption plume, or upper atmospheric wind conditions for a safe Shuttle launch, for example. Indirect, but closely coupled, applications include the wide range of physical forecasts, that is, forecasts which apply the laws of physics to the current and recent past status of the environment to predict its future state up to 10 days in the future. Physical forecasting depends not only

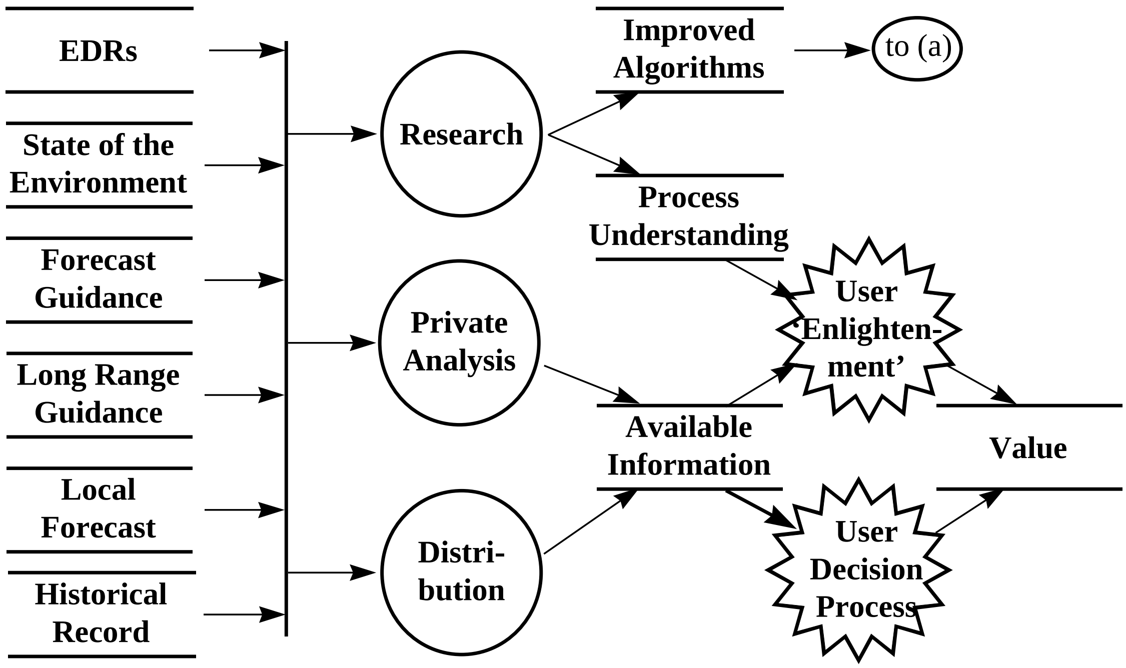

Figure 1-2b. Products to benefits: weather & climate example
All information products are available for direct distribution to users, for specialized analysis on behalf of users (*e.g.*, agricultural forecasts), and for scientific analysis. The latter will lead to improved understanding of environmental processes, quantification of long-range trends, factual support for policy recommendations, and development of improved forecast algorithms for the future. Individuals, industry, and government will use the information products to improve, on average, the value of their decisions relating to activities dependent on the environment. “Value” may consist of increased benefit, or decreased loss.

on the quality of the observations, but also on the quality of the physical models (algorithms) and computational power applied. The physical models are themselves derived indirectly from the accumulation of environmental observations over days to decades. Environmental observations accumulated over years leads to the ability to make rough climatological predictions based on empirical similarity, enhanced by limited analytical techniques. Least direct, the accumulation of environmental “wisdom” leads to long term understanding of environment processes and human activity, such as global climate change and stratospheric ozone depletion.

The benefits of environmental observation in general are realized by the application of this information to decision making under uncertainty. Before 1960, little other than local information (observations and climate) were available to make plans for activities depending on the environment. The uncertainty was large only two days in the future, resulting in conservative decisions and associated inefficient use of resources. Now we have global environmental observations and reasonable forecasting proficiency three to five days in the future, and can make more narrowly appropriate planning decisions. Even though a forecast may be imprecise, it has the ability to improve the overall quality of decision making above what would be achieved with climatological data alone.

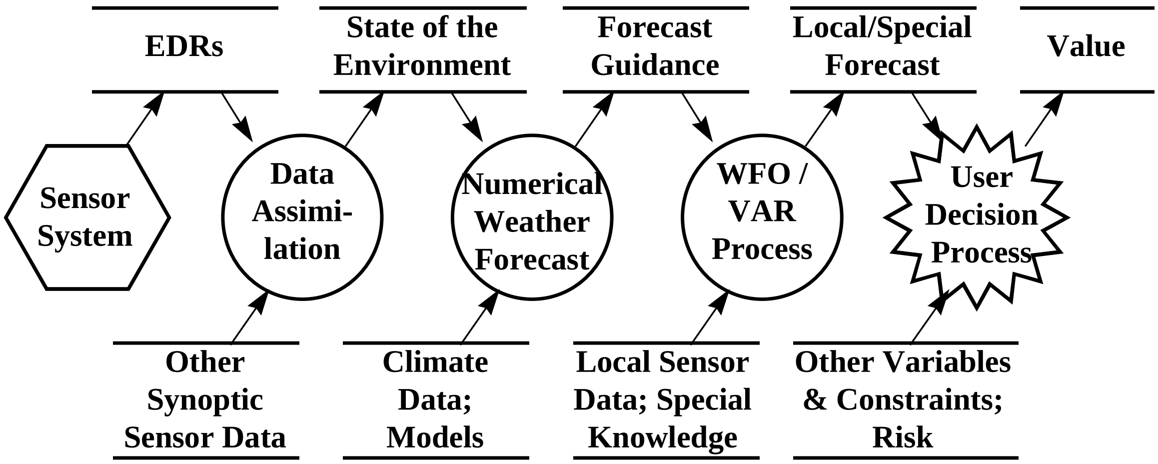

Figure 1-3. Multiple contributions to user value.
The analysis of the chain from sensor to value is significantly complicated by the many-to-many relationships involved. For any specific application, the contribution of a specific sensor or system – such as NPOESS – is diluted by contributions from other sensors, other knowledge, and other constraints and considerations in the decision process where value is determined. At the same time, major sensor systems contribute in some way to almost all human activities which can benefit from improved understanding of the environment. Certain applications have been emphasized in this study, because it is known that they depend on polar satellite observations to a relatively high degree. [*WFO* is Weather Forecast Office, *VAR* is value-added resellers of weather information.]

However, there is no one rule for *how* decisions are made under uncertainty. Every case is different, depending on application- and location-specific factors of costs, benefits, and a priori probabilities of outcomes. This problem will be discussed more in Section 3.

Finally, there is the question of whose benefits should be included. Certainly, direct cost savings to the US Government are relevant. Those which are anticipated to accrue to the polar satellite programs themselves (*e.g.*, combined procurement, communications, and mission operations) have been netted-out in the IPO cost plan. There are anticipated cost savings to other Government agencies, such as the US Coast Guard (USCG) for icebreaking and Bureau of Land Management (BLM), US Forest Service (USFS), the National Park Service, and Natural Resources Conservation Service (NRCS) for land management. Domestic businesses will benefit economically, and citizens will have both economic and societal benefits. This study has not included benefits which are enjoyed by US and foreign entities as a result of US polar satellite data being made available to all users worldwide. In some cases, the ability of the US civil agencies and firms to exploit this information may give them substantial benefits, such as drought assistance in Africa or forest fire monitoring in Borneo.

1.2 Benefits traceable to NPOESS

Although their aggregate benefit is extremely high, rarely can a specific benefit be traced to a specific sensor system or even a specific environmental factor (Figure 1-3). For weather applications, the process of "data assimilation" combines all available data into a consistent snapshot of the state of the environment at a specific instant, usually 00^h and 12^h Universal Time (UTC) every day. Data sources are direct measurements (ground observers, ships, buoys, aircraft, and balloons), indirect measurements (radar, geosynchronous satellites, polar satellites), and model predictions from earlier observations. Each data type is used based on a weighting which incorporates its estimated accuracy, timeliness, and relevance. The advantage is that all data can be used, and the best data will be used most. Table 1-1 shows the comparative characteristics of the major weather data sources. Polar-orbiting satellites provide particularly useful data coverage of oceans, arctic regions, sparsely inhabited and underdeveloped land areas, the troposphere above those regions, the upper atmosphere, and remotely sensed parameters which require calibrated worldwide collection.

It is generally accepted that environmental observation and weather forecasting are worthwhile activities. In the NPOESS context, the purpose of the study is narrowed by the fact that we are trying to estimate the *incremental* benefits to be anticipated from *incremental* improvements in polar sensors. There is an extensive literature of the societal and economic benefits of weather forecasting (Appendix E). This study has been limited to those areas where improvements in polar sensing will lead to discernible benefits to the civil community. Applications which benefit directly from NPOESS are limited to those which meet the following increasingly restrictive criteria:

1) activity or decision dependent on weather
2) activity or decision influenced by environmental knowledge
3) environmental knowledge traceable to polar platforms
4) environmental knowledge enhanced by polar platform improvement

1.3 Cost Considerations

It makes no sense to look for benefits without the context of the order-of-magnitude system cost to which they will be compared. NPOESS has documented system lifetime saving of $1.8B[10] compared with a baseline defined by continuing with evolutionary Block 6 and O,P,Q versions (respectively) of existing DoD and NOAA polar environmental satellites. Those satellites would have been enhanced to incorporate technological advances, increased data needs, and evolving standards. Major sensors

[10] IPO, *Report on Polar Convergence Operaitonal Benefits and Cost Savings*, 2 February 1998

Table 1-1. Major existing weather sensor systems[11]

Sensor System	Measurement Precision	Range	Resolu-tion	Timeliness
Automated Surface Observation System (ASOS)	high	49 states + partial Alaska; surface	high	immediate
Next Generation Radar (NEXRAD)	high	49 states + partial Alaska; troposphere	high	immediate
Balloons	high	N.Am.+; to lower stratosphere	low	12-24 hrs.
Buoys	high	offshore; surface	low	frequent
Geostationary Oper-ational Environmental Satellite (GOES)	low	hemisphere, S65-N65; troposphere	medium low	15 min.
Polar-orbiting Oper-ational Environmental Satellite (POES)	medium	global	medium high	4 hrs.

themselves must be redesigned for NPOESS, since the established joint civil and national security requirements will not be met with either existing sensor system. For example, the existing Advanced Very High Resolution Radiometer (AVHRR) cannot perform all functions of the Operational Line Scanner (OLS) (*e.g.*, low light level), nor can the OLS perform as the AVHRR (*e.g.*, vegetation index determination). A new Visible-Infrared Imaging Radiometer Suite (VIIRS) must be designed which meets, as a minimum, the threshold performance of both. Since redesign must be done, it is appropriate to incorporate the best current technology applicable to the sensing problem. The cost of incorporating best technology cannot, in general, be separated from the overall life cycle cost savings of the system. To the extent that there are marginal costs associated with improving performance at the outset, the overall cost savings may be reduced. Conversely, reducing some performance thresholds may not further reduce life cycle costs. In particular, redesign is always an opportunity to avoid the need for expensive upgrades in the future.

Of course, equivalent enhancements would have been required if the two polar environmental satellite programs had continued without convergence, and at a higher aggregate cost.

[11] National Weather Service, *Operations of the National Weather Service*, Silver Spring: NOAA, March 1996.

It would be convenient if we could find one application identified with each notional instrument suite (and its associated EDRs) that justifies the entire cost. Based on an extensive literature search and discussions with appropriate practitioners in meteorology and applied economics, we cannot find such overarching applications. It is clear, however, that multiple applications have been identified which provide the needed justification.

1.4 Differences in Establishing Civil and National Security Benefits

In the course of this study, it has become apparent that there are significant, subtle differences in the relationship between satellite environmental observations and application benefits in the national security and civil sectors. The differences (Table 1-2) include the context in which information is used, and the way in which benefits are evaluated. Although they do not change the results of the benefit analysis, they do influence the manner in which that the analysis is made and its thoroughness.

Previous COBRA studies have demonstrated the DoD-related aspects of these differences. Often, a weapon system has well-defined environmental requirements, environmental degradation expectations, and performance figures of merit (FOM). A guided munition requires certain visibility. Cloudcover and rain change the effectiveness of a fighter or bomber. Extreme high or low temperature limits the distance which can be marched. Vertical temperature, humidity, and wind influence the accuracy of artillery. Ground cover and ground moisture limit the mobility of mechanized units. Although the same environmental factors influence civilian life, there is no systematic procedure to quantify an "FOM" in civilian life.

Table 1-2. Comparative benefits analysis contexts

Characteristic	National Security	Civil
Complementary observations	rarely available	mostly available
Timeliness emphasis	current conditions	support NWF
Utilization	well defined	poorly defined
User performance FOM	well defined	poorly defined
Exclusive reliance on satellites	frequent	rare
Need for calibration & archives	limited	common
Coverage	global	primary: US & margins secondary: N. hemisphere
Experience with structured benefits analysis	established	novel

2. From Sensors to Products

The users' requirements identified in the Integrated Operational Requirements Document (IORD-I) are the basis for the NPOESS sensor suite. These requirements are applied to the environmental data records (EDRs) produced from sensor data. A listing of the complete set of NPOESS EDRs is provided in Appendix A.

It is important to emphasize that, with very few exceptions, the NPOESS EDRs have heritage in sensor data which are provided by current generation sensors. Table 2-1 shows that all NPOESS EDRs are necessary to fulfill needs which were validated before convergence of POES and the Defense Meteorological Satellite Program (DMSP). The detailed correlation between heritage sensors and current NPOESS EDRs was presented in Appendix D of the original COBRA report[12]. The sensor architecture is driven by the need to satisfy the users' data quality attributes (typically horizontal resolution and accuracy) defined for each EDR. Figure 2-1 shows the tightly coupled relationship between the NPOESS EDRs and the sensors that provide the necessary data sets to create each EDR.

2.1 NOAA Products

Products can be broadly classified into three types: forecasts, observations and climate predictions. Numerical weather forecasts (NWFs) are predictions of a future state of the environment based on observations, models of the environment physics, and the computer power to run these large, complex models. Forecasts are provided on a variety of time scales (near real time out to weeks), for a variety of phenomena (temperatures, wind, precipitation, etc.) for a variety of geographic regions, ranging from counties to global. NOAA estimates[13] that over 24,000 forecasts are issued daily for the United States. Since current forecasting is a science relying on observations as input into these models, the quality of the forecast will improve as quality of the input data improves.

Observations are products which, for the most part, are derived directly from sensor outputs and are not processed through models, only geolocated and converted from sensor parameters to environmental parameters. Examples of observations are: imagery, ice location and identification, sea surface temperature. Again, generally speaking, a finer horizontal resolution will allow for the proper identification and characterization of smaller scale phenomena.

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[12] IPO, *COBRA*, NOAA/IPO, June 1996.
[13] William H. Hooke, Case History: Short-Term Weather, *First Workshop on Prediction in the Earth Sciences: Uses and Misuses in Policy Making*, Boulder, Colorado, 10-12 July 1997.
Available at URL: http://www.dir.ucar.edu/esig/prediction/report1/case_histories.html

Figure 2-1. Relationship between EDRs and sensors

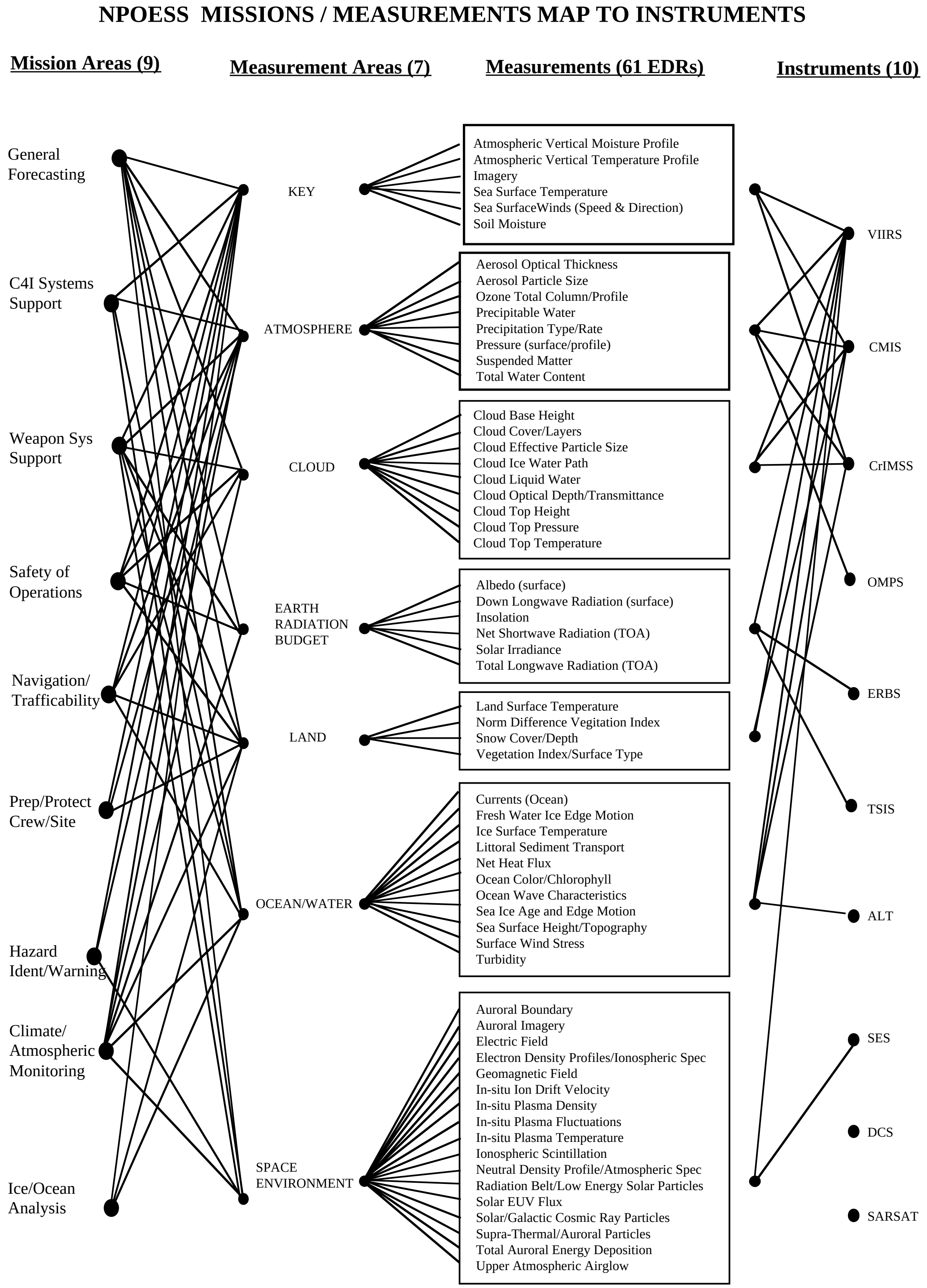

Table 2-1. Commonality between NPOESS EDRs and heritage satellite programs

	DMSP 5D3	NOAA K-N' (w/ METOP)	DMSP Block 6	NOAA OPQ (w/ METOP)	NPOESS
NPOESS EDRs					
Atmospheric Vertical Moisture Profile*	X	X	X	X	X
Atmospheric Vertical Temperature Profile*	X	X	X	X	X
Imagery*	X	X	X	X	X
Sea Surface Temperature*	X	X	X	X	X
Sea Surface Winds*	X	-	X	-	X
Soil Moisture*	X	-	X	-	X
Aerosol Optical Thickness	-	X	X	X	X
Aerosol Particle Size	-	X	X	X	X
Albedo	X	X	X	X	X
Auroral Boundary	X	-	X	-	X
Auroral Imagery	X	-	X	-	X
Cloud Base Height (New)	-	-	X	X	X
Cloud Cover/Layers	X	X	X	X	X
Cloud Effective Particle Size	-	X	X	X	X
Cloud Ice Water Path **(DOC)**	X	X	X	X	X
Cloud Liquid Water	X	X	X	X	X
Cloud Optical Depth/Transmittance	-	X	X	X	X
Cloud Top Height	X	X	X	X	X
Cloud Top Pressure **(DOC)**	X	X	X	X	X
Cloud Top Temperature	X	X	X	X	X
Currents (Ocean)	-	X**	X**	X**	X
Down Longwave Radiation (Surface) **(DOC)**	-	X	-	X	X
Electric Field	X	-	X	-	X
Electron Density Profiles/Ionospheric Spec	X	-	X	-	X
Fresh Water Ice Edge Motion	X	X	X	X	X
Geomagnetic Field **(DoD)**	X	-	X	-	X
Ice Surface Temperature	X	X	X	X	X
In-situ Ion Drift Velocity	X	-	X	-	X
In-situ Plasma Density **(DoD)**	X	X	X	X	X
In-situ Plasma Fluctuations **(DoD)**	-	X	X	X	X
In-situ Plasma Temperature **(DoD)**	X	X	X	X	X
Insolation **(DOC)**	-	X	-	X	X
Ionospheric Scintillation **(DoD)**	X	-	X	-	X
Land Surface Temperature	X	X	X	X	X
Littoral Sediment Transport (New - DoD)	-	-	X**	X**	X
Net Heat Flux **(DoD)**	X	X	X	X	X
Net Shortwave Radiation (TOA) **(DOC)**	-	X	-	X	X
Neutral Density Profile/Atmospheric Spec	X	-	X	-	X

* Key Parameters ** limited capability

Table 2-1. Commonality between NPOESS EDRs and heritage satellite programs (concluded)

	DMSP 5D3	NOAA K-N' (w/ METOP)	DMSP Block 6	NOAA OPQ (w/ METOP)	NPOESS
NPOESS EDRs					
Norm Difference Vegitation Index **(DOC)**	-	X	-	X	X
Ocean Color/Chlorophyll (New)	-	-	-	-	X[14]
Ocean Wave Characteristics (New)	-	-	-	-	X[15]
Ozone Total Column/Profile	-	X	-	X	X
Precipitable Water	X	X	X	X	X
Precipitation Type/Rate	X	X	X	X	X
Pressure (surface/profile)	X	X	X	X	X
Radiation Belt/Low Energy Solar Particles	X	-	X	X	X
Sea Ice Age and Edge Motion	X	X	X	X	X
Sea Surface Height/Topography (New)	-	-	-	-	X[16]
Snow Cover/Depth	X	X	X	X	X
Solar EUV Flux (New - DOC)	-	-	-	-	X[17]
Solar Irradiance (New - DOC)	-	-	-	-	X[17]
Solar/Galactic Cosmic Ray Particles	-	X	X	X	X
Supra-Thermal/Auroral Particles	X	-	X	-	X
Surface Wind Stress	X	-	X	-	X
Suspended Matter	X	X	X	X	X
Total Auroral Energy Deposition	X	-	X	-	X
Total Longwave Radiation (TOA) **(DOC)**	-	X	-	X	X
Total Water Content	X	X	X	X	X
Turbidity (New)	-	-	-	-	X[18]
Upper Atmospheric Airglow **(DoD)**	X	-	X	-	X
Vegetation Index/Surface Type **(DoD)**	X	X	X	X	X

Climate predictions refer to the longer term state of the global environment, such as El Niño. Climate prediction time scales run from months to years. Predictions are no more specific than temporal averages over regions, such as a dry summer in the Midwest, rather than the NWF objective of specificity, such as wind, temperature and precipitation for the next afternoon in a certain county. In certain applications, such as ozone depletion, the climate predictions range from years to decades. Although current climate prediction methods are primarily statistical, climate prediction is becoming increasingly more dependent on numerical models. Important for climate assessments are stability and consistency of the data collected over long periods of time, and the ability to observe

[14] Operational utility established by CZCS and SeaWiFS
[15] Operational utility established by Radarsat, NSCAT, etc.
[16] Operational utility established by TOPEX/POSEIDON and GEOSAT
[17] Operational utility established by ACRIM and SOLSTICE
[18] Operational utility established by CZCS and SeaWiFS

the phenomena sufficiently accurately over these periods of time (sometimes years or decades) to understand trends, and to detect subtle temporal and spatial relationships, known as “teleconnections”, of which ENSO is the most important. In particular, it is desirable to have sufficient confidence in trends and extrapolations into the future to use these results to influence public policy.

NOAA’s various component organizations produce a wide range of products and services for the public. These organizations include: National Weather Service (NWS), National Environmental Satellite, Data and Information Service (NESDIS), National Centers for Environmental Prediction (NCEP), Office of Atmospheric Research (OAR), National Ocean Service (NOS), and National Marine Fisheries Service (NMFS). As a sample, Table 2-2 lists some of the products routinely produced and distributed by the Government.

2.2 Assessing the Impact of Improved EDR Quality at the Product Level

The measure of civil benefit from a satellite system is the economic and societal impact. In order to evaluate the polar satellite contribution to public decision-making, the link between an EDR and a product (such as a forecast) used for decision-making must be identified. Furthermore, this link should be sufficiently detailed and well understood so that the relationship between *incremental* improvement in the satellite data and *incremental* improvement in the resulting product can be evaluated. Subsequently, the product improvements will be evaluated to understand their benefits to decision-making in the public and private sectors.

Figure 2-2 is an instantiation of Figure 1-2, as it applies to most NESDIS and National Centers for Environmental Prediction (NCEP) products. It shows that tracking the content flow is a difficult task, since the trail from EDR to product is not direct. Layers of processing and “value-added”, sometimes both internal and external to NOAA, often exist between the EDR and the information product used for public decision-making. Although historical trends indicate that there have been improvements in, for example, skill scores[19] over time, it is almost impossible to isolate a single cause. In addition to improvements in the quality of polar data, improvements in other data sources, developments in algorithm and models, and enhancements in processing power to run these models have also been made over time, all with interlocking dependencies. To accomplish the analytical comparison of incremental improvements in data from polar satellites, holding all other sources and value-added processes constant, requires a significant investment in personnel and computer resources.

[19] Kalnay, E., Kanamitsu, M., and Baker, W.E., Global numerical weather prediction at the National Meteorological Center. *Bulletin of the American Meteorological Society*, **71**, 1410-1428, 1990.
“Skill scores” are quantitative measures of the amount by which forecast accuracy exceeds climatological expectations.

Table 2-2. Some Standard Environmental Products from Polar Satellite Data

NCEP Center	*Sample of Products*	
Aviation Weather Center	• Airmets (AIRman's METeorological Information) • Area Aviation Forecasts • Sigmets (SIGnificant METeorological Information) U.S, International • METAR	• Transcribed Weather Broadcast (TWEB) Route Forecast • Winds aloft forecast • Wind/temperature plots • Alaska Aviation Weather • Terminal Aerodrome Forecasts (TAF)
Hydrometeorological Prediction Center	• 12, 24 hour forecasts of fronts and precipitation • Surface Analysis (North American, Pacific) • Short Range Public Forecast • Quantitative Precipitation Forecasts	• Medium Range Forecast Products: -Days 3, 4, 5 Surface Prognostics -Day 3 Temperature Anomalies -Days 4 and 5 Temp Anomalies • International Forecast Products - South America, Caribbean
Space Environment Center	• International Space Environment Service (ISES) • State of ionosphere on Radio Users	• Auroral Activity • State of space environment on Navigation Systems -Warnings, alerts
Climate Prediction Center	• Climate Outlooks -6-10 Day, monthly, seasonal • Climate Data -Degree Days -Precip/Temp Tables	• Weekly Global Climate Highlights • Special Summaries -Flooding in the Pacific NW -Drought in the Southern Plains • Ultraviolet Index (with EPA)
Storm Prediction Center	• Day 1 Convective Outlook • 2nd Day Severe Outlook	• Tornado and Severe TS Watches • Mesoscale Products
Marine Prediction Center	• High Seas Forecast (Atlantic, Pacific) • Marine Interpretation Message (MIM) Forecast	• Regional Surface Forecast • Regional Wind/Sea State Forecast (24 hr, 48 hr 500 mb)
Tropical Prediction Center	• Tropical Cyclones (Atlantic, Eastern Pacific) • Latest Tropical Weather Outlook (Atlantic, Pacific)	• Latest Monthly Tropical Weather Summary (Atlantic, Pacific) • Satellite Rainfall Estimates
Environmental Modeling Center	• Ocean Modeling Branch -Coastal US Visual Range Guidance -Satellite Derived Ocean Surface Winds -Global Wave Model -Polar and Great Lakes Ice Group -Ocean Fog Model -Ship Superstructure Ice Accretion Model	• Global Modeling Branch -NCEP Ensemble Products • Mesoscale Modeling Branch -10km Eta Tiled Output -Forecast and Observed Precip Plots • Applications and Systems Group -Aviation Wind Correction

Recognizing, however, that this is an important effort for future analyses of sensor development, a process to accomplish this type of comparison, the Observing System Simulation Experiments (OSSEs), has been initiated by NOAA and the NPOESS IPO. One objective of the OSSEs is to provide the analytical framework for such sensor comparisons. More on the OSSEs can be found on the Internet (URL: <http://nic.fb4.noaa.gov:8000/research/osse/index.html>).

Although the OSSEs will provide a partial solution to the very complicated problem of quantifying the improvement in forecasts due to sensor improvements (and, therefore, EDR quality), these answers will not be available for payload optimization until late

Table 2-2. Some Standard Environmental Products from Polar Satellite Data (concluded)

National Weather Service [20]	***Sample of Products***	
Interactive Weather Information Network	• Local weather - reports - forecasts -watches, warnings, advisories	• National items - agricultural summaries - flood, hurricane, earthquake, tsunami reports
Graphics (FAX) Charts	• Analyses - pressure, wind, significant wx • Watches & warnings • Thunderstorm probability • Freeze level • Humidity • Volcanic ash	• Forecasts - 12, 24, 36, 48, 60 hour - 3, 4, 5, 6-10 day - pressure, winds, humidity, waves • Monthly, seasonal outlooks - temperature, precipitation - crop moisture, drought
Fire Weather	• Current Conditions	• Fire Weather Outlook
National Operational Hydrological Remote Sensing Center (NOHRSC)	• Snow cover	• Snow water equivalent
Other Agencies	***Sample of Products***	
NESDIS/ARGOS	• Data Collection System - environmental science transmitter data - environmental hazard monitoring data	• SARSAT
National Ice Center[21]	• Arctic, Antarctic, and Great Lakes Ice - coverage, concentration, development	
EDC/US Geologic Survey[22]	• AVHRR LAC imagery	• Biweekly NDVI composite map
USDA	• Foreign Production Estimates and Crop Assessment[23]	• Domestic crop condition assessments[24] • Weekly Weather and Crop Bulletins[25]
CoastWatch Program[26]	• Sea surface temperature	• Ocean color products

1998. The first results will include a sensitivity evaluation of sounders and wind sensors. In the meantime, a qualitative analysis was undertaken by the IPO which initiated detailed tracing of users and potential beneficiaries of better quality data. It was decided that one way to attempt to isolate significant uses/users of polar satellite data was to begin with the NOAA product developers, and trace through the production process to

[20] Available at URL: http://www.nws.noaa.gov/data.shtml
[21] Available at URL: http://www.natice.noaa.gov/
[22] Available at URL: http://edcwww.cr.usgs.gov/dsprod/prod.html#satellite
[23] FAS Production Estimates and Crop Assessment Division, URL: http://www.fas.usda.gov/pecad/remote.html
[24] National Agricultural Statistics Service, URL: http://www.nass.usda.gov/research/rdsars.htm
[25] Joint Agricultural Weather Facility, URL: http://www.usda.gov/oce/waob/jawf/
[26] Available at URL: http://psbsgi1.nesdis.noaa.gov:8080/PSB/EPS/CW/coastwatch.html

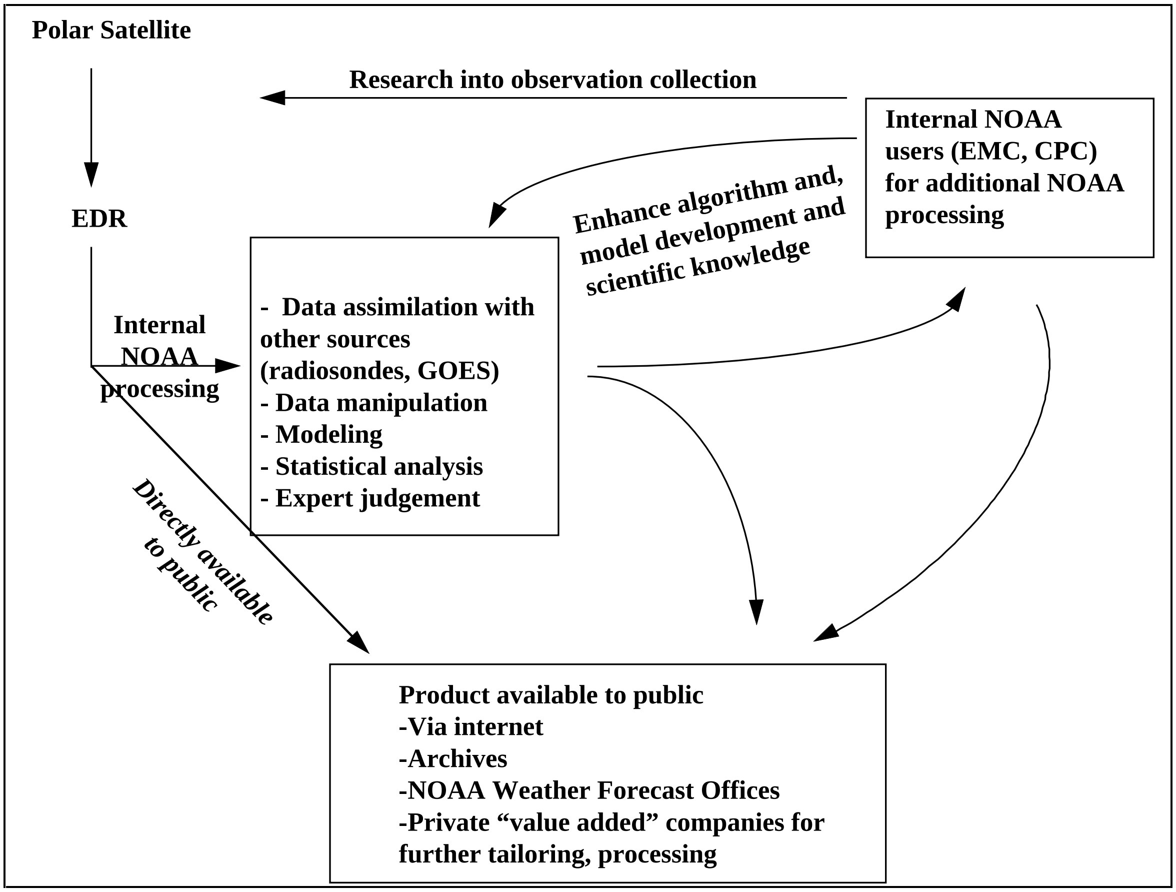

Figure 2-2. EDR to NOAA Product Formation

immediate known users of the data. The recommended strategy was to work with the Product Oversight Panels (POPs), organizations within the NOAA environmental offices responsible for the research, production and distribution of environmental products, of which the polar satellite products are a subset. A survey requesting users/uses of the data was sent to panel representatives and subsequent interviews were held. Appendix B summarizes the individuals interviewed, their organizations and the topics.

2.3 Summary Findings

A few of the recurring themes found throughout these interviews are summarized here.

• Numerical weather prediction relies on the complex interaction of observational data, algorithm advancements and processing power. Forecasting skill has improved over the years[27] due to a collective improvement in these three areas. As described above, isolating the effects of sensor improvements alone has not been possible. The OSSEs are intended to provide some of these answers in a rigorous fashion.

• The quality (in terms of accuracy and horizontal and/or vertical resolution) of EDRs that are required for numerical weather prediction is driven by modeling structure. With more available processing power, the amount of data that can be processed for operational forecasting has increased so that models are increasingly relying on observations over a smaller grid size. In doing so, the modelers are beginning to approach the problems and advantages of mesoscale phenomena, such as convection and turbulence. The scientists interviewed confirmed previous statements of the justification for improving quality of the EDRs, namely, that the resolution of the data must keep pace with the resolution of the models.

• With respect to direct observations (like imagery of ice and sea surface temperature), the desire to obtain smaller-scale resolution (for example, 1 km grids versus 10 km grids) is to improve the ability to detect small scale phenomena that are important to some sector of the public. Whereas a general modeling link between improving specific imagery resolution and impact to the economy does not exist, cases of specific users and their need for the information can be found in the literature, and their individual assessment of the value of higher resolution to their needs, or the consequences of not getting the necessary resolution can be explored. Some examples of these case studies are:

- Ice breaking operations in the Great Lakes are more efficient with more accurate location of thinner ice.

- Sea surface color and temperature changes on a small scale (for example, around coastal areas, estuaries, rivers, bays) can suggest the presence of harmful effects (toxic blooms, “red tide”) or beneficial conditions (food sources for fish) that are used by fisherman and regulators to manage the fishery effectively and profitably.

- The improved precision and resolution with which actual groundcover conditions are determined from space will reduce a contributing error source in numerical weather forecasting as the cell size of the modeling mesh shrinks. Similarly, long range forecasting errors be reduced by the improved determination of boundary conditions, *e.g.*, soil type and moisture, snowcover, vegetative cover type and maturity.

It is clear from these few examples, and many more that were mentioned briefly during the interviews, that it is possible to enumerate specific areas of economic benefit directly influenced by polar satellite data and to conduct economic analyses on the impact of improved data. This case study method has merit in that it is focused on specific industries (or for specific companies) so that data can be obtained and analyzed. As

[27] Kalnay, *et al., op. cit.*

mentioned in Section 1, however, the shortcoming of such investigations on a case by case basis is that it is very difficult to extrapolate from a small collection of benefit areas to the larger economy.

3. From Products to Benefits

Environment-related decisions are based in part on products such as those listed in Table 2-2, in addition to other constraints and considerations. In this section, the characteristics of decisions based on environmental information will be described, examples given, and proposals made for how discrete examples should be put in context to be compared with NPOESS costs. This section also contains an enumeration of the civil applications which are expected to benefit from improvements embodied in NPOESS.

3.1 Information Flow from Products to Civil Benefits

Environmental products have "value" and enable socioeconomic benefits to the extent that they can improve the decision-making process. Decision making may use current conditions ("We've begun to descend. Is it raining at the airport?"), or long range forecasts ("What crop should I plant this season?"). It may be formal ("What is the optimum cement composition that will properly cure over the next two days, given that if it gets too cold I have to do it over?") or informal ("Can we have the party outside on Saturday?"). It may involve millions of dollars ("Should we close the federal government for snow tomorrow?), or trivial inconvenience ("Should I take a hat?"). Finally, it may occur once in a decade ("Will Hurricane Andrew hit Miami?"), or billions of times per year ("What should I wear?). The overall impact on society depends on the product of the weather-related benefit of each decision-event, and the number of such decisions. Figure 3-1 shows how some environmental decisions *could* look when plotted together. Because the scales are logarithmic, the locus of a constant net impact is a straight diagonal line. The figure highlights the point that it is not obvious whether frequent, small events are more significant than infrequent, large events.

Although it might be possible to estimate the aggregate value of improved environmental information to society (macro approach), this study has investigated ways to estimate the value of individual decisions or classes of decisions (micro approach). Ultimately, the micro approach may be used in one of two ways. There may be one or a few applications which will benefit so strongly from NPOESS enhancements as to justify the cost of those enhancements. Alternatively, an enumeration of all the major applications, "calibrated" by a limited number of applications with quantifiable benefits, can be extrapolated to an estimate of the total socioeconomic benefit.

In all cases, the benefits must be parameterized in terms of an assumed quality of improvement for the associated environmental product. This itself is often a value judgment, and can be refined in the future.

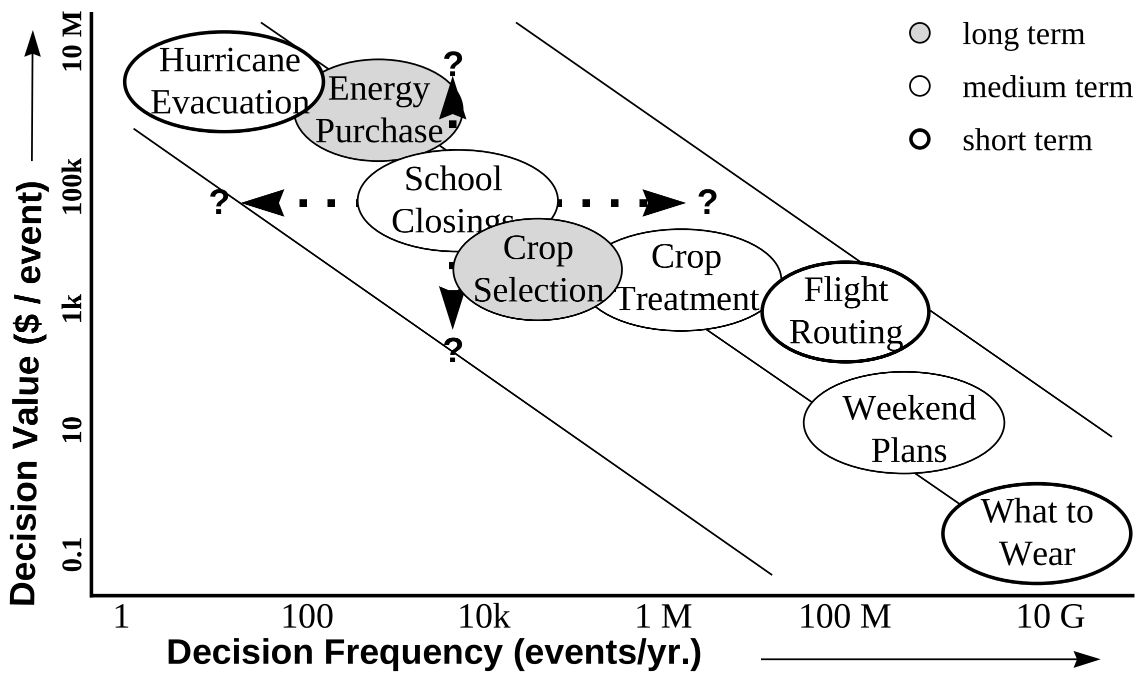

Figure 3-1. The aggregate value of weather-related decisions depends on individual value of each decision and frequency with which it occurs. *Note: numerical values are rough estimates for illustration only.*

3.2 Study Methodologies

3.2.1 Qualitative

As a result of the interviews described in Section 2 and an extensive literature search (see Bibliography in Appendix E), the IPO has produced a preliminary catalog of specific socioeconomic benefits which are considered candidates for improvement from NPOESS enhancements. The catalog consists of two parts: a narrative description of the application and its relationship to environmental knowledge, and a qualitative evaluation of the significance of the benefits attributable to NPOESS.

An overview of the catalog classification scheme is shown in Figure 3-2. The lower portion shows a more detailed breakdown for one entry. The catalog is found in Appendix C.

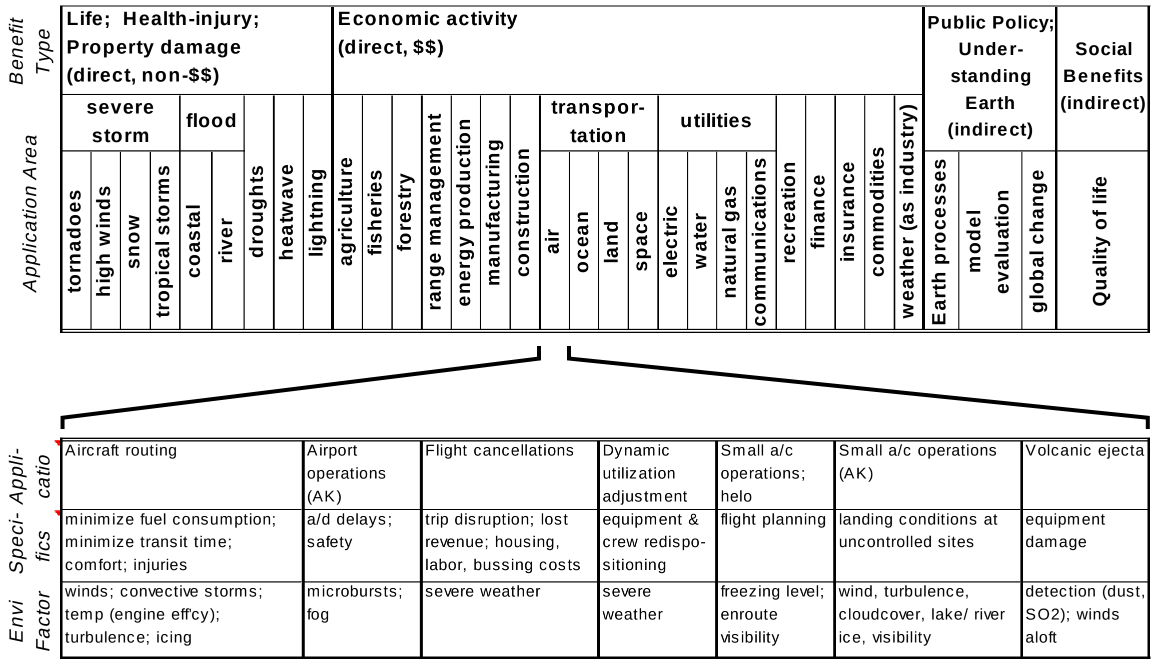

Figure 3-2. Taxonomy of benefits

For classification and convenient groupings, types of benefits have been categorized in Appendix C in a manner similar to that shown here. At the highest level, benefits are divided into principally economic (monetary) or societal (non-monetary), direct and indirect. Economic benefits are further subdivided into individual primary, secondary, and tertiary industries. Societal benefits are subdivided into the type of relationship between man and the environment involved. Each specific application area is associated in the catalog with one or more aspects which may benefit from environmental information.

The qualitative evaluation is a useful tool for identifying those applications which are most likely to be significant contributors to the overall socioeconomic benefits from NPOESS.

3.2.2 Quantitative

For individual applications identified through qualitative evaluations, it may be possible to locate existing or collect new data which allows quantitative benefit estimation. Unfortunately, most studies[28] have been produced either for narrow applications, or as examples of tractable and characteristic problems. One reason that wide applications, such as those which involve entire markets, are not analyzed is that such applications often use weather as a "public good", which is the rationale for weather information being provided by the Government to all[29].

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[28] Johnson, Stanley R. and Matthew T. Holt, The Value of Weather Information, Chapter 3 in Katz, Richard W. and Allan H. Murphy, Eds., *Economic Value of Weather and Climate Forecasts*, Cambridge: Cambridge University Press, 1997, Table 3.1

[29] Anthony, Robert N. and Regina E. Hertzlinger, 1975, *Management Control in Nonprofit Organizations*, Richard D. Irwin, Inc., chapter 7.

There is no single technique for quantitative benefit calculation. In general, the environment (weather) causes an increase or decrease in the value of an item or an activity. A weather *forecast* allows some action to be taken, at some cost, which will tend to maximize the increase or minimize the decrease in value. *Uncertainty* in a weather forecast means that the optimal action will not be known in advance, and the action taken will depend on the cost-loss distribution associated with the range of possible weather conditions, and the unacceptability (economic or other) of certain outcomes -- risk aversion. For example, the forecast of a hurricane landfall leads to the securing or removal of property (at some cost), and the evacuation of people (at some cost and inconvenience), to minimize *possible* damage and injury. Because a hurricane's forecast track and flooding are not exactly predictable, and because the penalty for error (risk aversion) is so high, warnings and evacuations cover more area and people than would actually be significantly hurt by the storm. Furthermore, the individual decision processes are different from the governmental process, since individual cost-loss, risk aversion, forecast uncertainty, and economic/inconvenience decision criteria are not the same as governmental emergency management policies.

Well formulated case studies of economic benefits will hold all but one weather-related parameter constant. The parameter can be used in the economic decision model at any of four levels of precision: (1) ignored; (2) climatological value adopted; (3) forecast value adopted; or (4) correct *post facto* value adopted. For the purpose of this analysis, studies which allow estimating change in benefit from (2) or (3) toward (4) have been most useful. Examples are given below.

3.3 Constraints

In each case study, the original author has been relied upon to have collected and analyzed his data properly, and described any assumptions or limitations. Where possible, assumptions have been adjusted to match the need to estimate *incremental* changes in economic benefits associated with *incremental* improvements in sensor performance.

Without the results from the OSSEs described in Section 2, product improvements must be estimated in most cases. Typically, one percent improvements are considered conservative for those products which depend strongly on polar satellite sensors, and are adopted here as a starting point. Assumptions will be revised as appropriate before the civil benefits study is complete.

3.4 Case Studies

This section contains four case studies which estimate rough order-of-magnitude benefits of NPOESS data. Table 3-1 summarizes these results, which are discussed in the following subsections.

Aviation routing and electric power generation are believed to be two of the largest identifiable beneficiaries of improved sensor data, and may represent an upper bound on annual economic benefit for an application. Airline routing and electric power are also two of the industries best structured and motivated to use improved forecast information, since they already have extensive experience in profitably applying forecast information.

Many more potential benefit areas have not been quantitatively evaluated for this report, and are similarly dependent on polar satellite data (see Appendix C). Thus, notwithstanding the limitations of the estimation techniques used, these rough order-of-magnitude (ROM) estimates represent a lower bound to a significantly higher dollar value for potential benefits.

Table 3-1. Summary of NPOESS economic benefit case studies

Case Study	Annualized Economic Benefit (1997 dollars, in millions)
Aircraft routing	$15
Electric power generation	$33
Washington state orchards	$ 4
Landsat remote sensing	$ 5
Total from Case Studies	*$57*

3.4.1 Case Study: Aviation: Commercial Airline Route Optimization for Wind and Atmospheric Profile

Within the next ten years, "free flight" will be adopted as a mechanism to improve aircraft routing in the US. Free flight replaces the highway-in-the-sky paradigm in use now with an open field paradigm. Each aircraft will fly from origin to destination along the best route which avoids other aircraft, not along routes defined from one established waypoint to the next. One part of the advantages of free flight is the ability to use the shortest path. The other part is the option to use meteorological forecasts to take the quickest or most efficient path with suitable comfort. The path selection will depend on wind, pressure levels, humidity, temperature[30], convection, and (during ascent and descent) clouds, precipitation, and freeze level.

A Federal Aviation Administration (FAA) draft report[31] has calculated the economic benefit from optimized aircraft routing in the US over the period 2006-2016[32]. Other

[30] Humidity and temperature effect engine operation efficiency.
[31] *Cost-Benefit Analysis of the Wide Area Augmentation System (WAAS)* (draft), FAA, July 1997

studies have predicted that the average flight segment will be reduced by at least one minute[33]. Taking into account aircraft operating costs and the value of passengers' time, and adopting the FAA assumption that 30% of flights achieve this reduction, the total economic savings average about $1,005M (FY97) per year over the period examined. The General Accounting Office (GAO)[34] has substantially agreed with the FAA analysis.

The next step is to estimate what fraction of the benefit can be attributed to NPOESS data. Modern turbojets travel at flight levels which are only well monitored by polar satellites, balloons, and other aircraft. The estimated contribution of specific weather forecast beyond climatic means (*e.g.,* the general westerly trend of the jet stream, or the typical vertical temperature, pressure, humidity profile) is 30%. The estimated contribution of polar sensors to forecasts of temperature, pressure, humidity, and wind at these levels is 50%, since the only other contributions are from other aircraft and rawindsondes, which provide very limited data samples. The estimated overall improvement in quality of the applicable forecast parameters attributable to improved sensor performance is 10%. Combining these, the economic benefit of free flight, attributable to improved NPOESS data, is

$$0.30 \times 0.50 \times 0.10 \times \$1{,}005M = \$15.1M \text{ (FY97) per year}$$

Similar Applications

In addition to optimal routing, aircraft operators need warnings of severe weather to avoid delays, diversions, and cancellations at the destination, and uncomfortable or dangerous turbulence enroute. With reliable advanced warning, airlines could redeploy equipment and crews before a storms closes down an airport. Convective instability, which may lead to "clear air turbulence" or other sudden violent motion, is a particular concern because of injuries, occasional deaths, and significant liability risk.

The problem of ocean ship routing has some similarities, since slow bulk carriers, for example, would like to take maximum advantage of currents such as the Gulf Stream.

3.4.2 Case Study: Utilities: Temperature Forecast Errors

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[32] Over the later time period appropriate to NPOESS, the average savings would be higher under the FAA traffic forecast model.

[33] Final Report of RTCA Task Force 3, Free Flight Implementation, October 26, 1995 and Air Transport Association Study, February 1994, quoted in (FAA, 1997)

[34] Dillingham, Gerald L., *National Airspace System: Observations on the Wide Area Augmentation System* (testimony), Washington: GAO/T-RCED-98-12, 1 October 1997
Endorses the savings calculated in the WAAS CBA.

As an example of the economic impact of weather forecasting errors, Keener[35] has analyzed the relationship of forecast error and inefficient use of power generation facilities at Duke Power. Electric and gas companies forecast their daily power load on the basis of the expected weather. The most critical variables are, in order of effect, temperature (T), relative humidity (RH), cloud cover, and wind. The Duke forecast model uses hourly forecasts of T and RH and predicts the hourly load for a forecast period of eight days. Specifically, Keener determined that a forecast error of 5° F results in an error in generation load of 600 MW to 1000 MW. The typical cost of operating a coal fired generation unit with an output of 500 MW is $250k per day. A combustion turbine unit has an operating cost twice that of the coal powered unit, and is used as backup when demand exceeds the supply which can be handled by coal. The unanticipated demand due to a forecast error of 5° F thus costs $500k per day in production cost. Over the course of a year, Duke Power estimates losses of at least $8 million (1996 dollars) for effects due to all weather forecast errors. The mean absolute error in next day maximum and minimum temperature in the conterminous U.S is 4.2°F[36].

Keener's analysis for Duke can be used to estimate the effect for the US electric industry as follows. The total generated power in the US[37] in 1996 was approximately 3080 billion kilowatt-hours (G-kWh), of which Duke Power[38] produced 76.9 G-kWh, or 2.5%. If the Duke Power area is typical of the US for the distribution of temperature forecast errors, and the cost structure at Duke power is typical of the US industry, these events represent a total excess production cost of approximately $320M per year for the US[39]. Thus even a 0.2 C (10%) reduction in the absolute temperature forecast error due to the improved capability of NPOESS would represent a savings of $32M (CY96) per year in electric power generation in the US.

Similar Applications

The natural gas industry is subject to similar weather-driven demand planning pressures. The problem differs, in that it involves long term purchase agreements, and shorter term distribution and storage decisions. Improper planning leads to either the purchase of expensive gas supplies on the spot market, or suspension of delivery to industrial customers in the case of shortages.

[35] Keener, Ronald N., Jr., The Estimated Impact of Weather on Daily Electric Utility Operations, *Workshop on the Social and Economic Impacts of Weather*, Boulder, 2-4 April 1997

[36] Dagostaro, V.J. and Dallavalle, J. P., AFOS-era verification of guidance and local aviation/public weather forecasts -- no. 23 (October 1994 - March 1995), Techniques Development Laboratory Office Note 97-3, NWS/OSD, August 1997. Table 2.1.

[37] Energy Information Administration (EIA), *Homepage*, DOE, URL: <http://www.eia.gov/> (8 Jan 98)

[38] Duke Power Company, *1996 Annual Report*, URL: < http://www.duke-energy.com/ investors/reports/1996/duk/Year_Review.pdf>

[39] Based on $8M per year corresponding to 2.5% of the US industry. Duke Power uses a typical mix of coal, gas, nuclear, and hydro power generation. Hydo power is not generally available to compensate for inaccurate temperature prediction.

Electric power bulk distribution[40] capacity depends on weather, as well. High power trunk line carrying capacity forecasts depend on ambient temperature and, most significantly, minimum wind speed along the line. In the coming competition among suppliers, distributors will need to carry the greatest possible amount of energy from the low-cost producers to the large demand centers.

3.4.3 Case Study: Agriculture: Orchard Freeze Warnings

This case study constructs a quantitative monetary estimate of the economic value of improved frost and freeze warnings for orchardists in Washington state. We have selected this specific operational benefit simply as a matter of convenience: several published studies[41] have addressed the issue of the economic value of NWS frost forecasts to orchardists in the Northwest. Our estimates of the value added by NPOESS are based on that research, and on a number of assumptions that are explained below.

In 1976, Baquet *et al.* estimated that the value per day per acre of NWS frost forecasts for pear orchardists in Jackson County, Oregon was approximately $5.00 during the 60-day frost danger period, or $300 per acre per year. Though not stated in the paper, we assume that the reported values are in 1972 dollars (as the paper was originally drafted in 1974).

In 1982, Katz *et al*. used a prescriptive (or normative) Markov decision model to estimate that the annual value per acre of NWS forecasts to orchardists in Washington's Yakima valley was approximately $270 for peaches, $492 for pears, and $808 for apples (all in 1977 dollars). Note that the value ascribed to NWS frost forecasts for pear orchards is reasonably consistent with the value found by Baquet *et al*.

In 1984, Stewart *et al*. revisited the 1982 Katz *et al.* study, using a descriptive rather than prescriptive modeling approach. Their overall results were quite similar, confirming the apparent reasonableness of the previous estimates.

In our calculations below, we use the values reported in the 1982 study. By weighting the reported values for the several crops with their planted acreage (using 1996 acreage data[42]), and assuming the calculations can be extrapolated to all of Washington state, we

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[40] Fuldner, Arthur H., Upgrading Transmission Capacity for Wholesale Electric Power Trade, DOE Energy Information Administration, 9 April 1997 [available:] URL:
<http://www.eia.doe.gov/cneaf/pubs_html/feat_trans_capacity/w_sale.html>

[41] Baquet, Halter, and Conklin, "The Value of Frost Forecasting: A Bayesian Approach" *The American Journal of Agricultural Economics*, Vol. 58 (1976), pp. 511-520.

Katz, Murphy, and Winkler, "Assessing The Value Of Frost Forecasts To Orchardists: A Dynamic Decision-Analytic Approach" *Journal of Applied Meteorology*, Vol. 21 (1982), pp. 518-531.

Stewart, T.R., et al, 1984: Value of weather information: a descriptive study of the fruit-frost problem. *Bulletin of the American Meteorological Society*, **65**: 126-137.

[42] "Washington 1997 Annual Bulletin, Fruit Acreage, Production, And Value" (http://www.nass.usda.gov/wa/annual97/fruit297.htm).

calculate a weighted average annual value to orchardists of $767 per acre (in 1977 dollars) for frost and freeze warnings.

Assuming that the secular trend of prices and costs faced by orchardists has followed the Consumer Price Index (CPI), we find that the corresponding 1998 value per acre of NWS frost forecasts is $2082.

In 1996, there were, according to US Department of Agriculture (USDA) statistics, 234,400 acres of fruit and nut orchards in Washington state (of which 2/3 were apple orchards). In our calculation, we assume that that acreage remains constant into the future, and we assume that the weighted average annual value of NWS frost forecast of $2082 per acre applies to all Washington orchard acreage.

In order to estimate the value of NPOESS to Washington orchardists, we make additional assumptions. First, we assume that NPOESS will not have any impact on forecasts until the year 2008, at which point it will add 0.83% to the value of the non-NPOESS NWS frost forecast. The added value reflects the potential improvement in accuracy and lead time for NWS frost forecasts. The added value is akin to the benefit of reducing the frost danger season by one day out of 60 over half of the crop. This value added is assumed to begin in the year 2008, and remains constant thereafter. We note that our sources show that the value of the then-current NWS frost forecast was substantially less than the value of a perfect forecast. In other words, the NWS forecast is imperfect, and there is ample room for improvement in the frost forecasts. NPOESS will accomplish a bit of that improvement.

We adopt a time horizon for our analysis of 1998 through 2025. Over that time horizon, we assume that the CPI increases at 2.5% annually. To bring forward historical values over the years 1975 through 1997, we use the actual CPI as reported by the U.S. Bureau of Labor Statistics.

The savings per year in 1998 dollars is $4.06 million. After applying a real discount rate of 3.5% to future savings, the present value of NPOESS' incremental contribution to frost forecasts for Washington orchardists is $39.3 million dollars.

This value alone is a significant fraction of any anticipated incremental cost of the NPOESS enhancements. The assumptions involved are notional but reasonable, producing a reasonable result.

Similar applications

While this value alone is a significant fraction of the (present value of the) incremental cost of the NPOESS, it must be interpreted as a small percentage of the likely total (all crops, all regions) national agricultural benefit; and as a very small percentage of the likely total (all impacts, all regions) society-wide benefit. The total fruit and nut acreage in Washington (used in this illustrative calculation) is only about 6% of the nation's total. Other major areas of fruit production, which would likely benefit from NPOESS, include California (apples, peaches, pears, grapes and citrus), Florida (citrus), South Carolina and

Georgia (peaches), and New York, Michigan and Pennsylvania (apples). In addition, there would likely be some benefit of improved frost forecasts to other crops as well.

3.4.4 Case Study: Land remote sensing: Landsat cloud avoidance

Landsat 7[43] is a sun synchronous land remote sensing satellite which provides the US with global imagery every 16 days. The operating concept is to fill global land surface archives with substantially cloud-free images. The archives will be updated as efficiently as possible to permit multitemporal analysis of land surface processes (seasonal variations in natural land-cover, agriculture, coastal changes, etc.). There are about 730 potential land scenes (170 km x 185 km) per day in view from the satellite. Due to onboard storage and communications limitations, only about 230 can be collected and returned to the US Geologic Survey (USGS) archives in Sioux Falls, SD. Thus, yield and performance are optimized by taking the "best" scenes, not wasting onboard resources with either cloudy or duplicate scenes. Collection planning takes place about 36 hrs. before a scene is imaged.

Without any cloud cover predictions, about one third to one half of scenes would not meet the acceptance criteria. The collection capacity has little margin beyond what is needed to collect all (and only) the cloud-free scenes. Thus, in most cases, a cloudy scene taken means that a cloud-free scene will be missed.

The Landsat program cost is estimated at $728M (current) for acquisition and launch, plus operations and data processing costs at NOAA and USGS for a five year mission, for a total of about $1B. Existing cloud statistics and forecast quality metrics demonstrate the advantages of using cloud cover predictions to improve surface imagery yield[44]. Every 1% reduction in cloudy scenes (1/3 of total available) improves the return to the Government by: 1% x 1/3 x $1B = $3M.

Beyond this, there is a loss to the land remote sensing community based on the absence of otherwise useful imagery. The commercial price of a Landsat 4/5 scene is approximately $4,000. Landsat 7 scenes will be more valuable (higher resolution, better calibrated), so the estimated commercial value will be nearer $5,000. Assuming 30% of the archives has commercial value, each 1% reduction in excessively cloudy scenes will increase the number of commercially valuable scenes each day by

(1% improvement) x (1/3 cloudy) x (30% useful) x (230 scenes) = 0.23 scenes

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[43] Goldberg, A., Quantitative Effect of Cloud cover, [MITRE briefing to the Landsat Project Office, Code 420, GSFC], 20 September 1994. Compares alternative strategies for collecting nearly cloudfree ground imagery under Landsat operational constraints and inexact cloud cover forecasts.

[44] Harriman, Ed, Weather Forecasts: A Resource Multiplier for Landsat 7, Martin-Marietta AsroSpace, 22 December 1993. Compares the collection efficiency resulting from alternative cloud cover forecast accuracy and update assumptions

and the total archives value to the user community by

(0.23 scenes per day) x (365 days) x (5 years) x ($5,000 per scene) = $2,100,000.

The higher spatial resolution, improved all-weather performance, improved precision of NPOESS imagers and sounders, and the improved detection of surface and stratospheric boundary conditions will enable improved forecasting of cloud cover, especially as applied to global programs such as Landsat. Assuming a 5% reduction in excessively cloudy images, the total economic benefit over the five year program is $25.5 million (CY97).

Discussion and similar applications

The Landsat case illustrates a class of application for which US industry needs global environmental data.

Most US commercial satellite remote sensing programs and some scientific instruments (such as ASTER on EOS-AM1) can benefit in a similar way[45], conserving limited resources (power, digital memory, communications access time, quick-look processing) for useful imagery only.

[45] Goldberg, A., Cloud cover and Land Remote Sensing: Comparison of Operational Constraints, [MITRE briefing] Science Working Group for the AM Platform (SWAMP) meeting, 2 March 1995
Describes the impact of unknown cloud cover on resource-constrained ground imaging collection

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4. Conclusions

Polar environmental satellite technology supports direct and indirect, monetary and non-monetary civil benefits. Over different time spans, these satellites provide information which leads to understanding the current state of the environment, its future state, its underlying processes, and its susceptibility to human activities.

Polar environmental satellites possess certain unique characteristics. They observe the entire globe with the same sensor, permitting systematic, calibrated observations. They cover large areas of the globe inaccessible or poorly sampled by other sensor systems, such as the oceans, the arctic, and the upper atmosphere. Information products which predict the long range state of the environment depend critically on this "synoptic" coverage. Even short range forecasts for US territories adjacent to undersampled regions (such as Alaska and the West Coast) benefit from the advanced warning of the airmasses and controlling forces which make the weather there.

In constellations of three or four, polar satellites cover the temporal changes in the environment over time spans from hours to decades. The long term historical record allows environmental phenomena to be studied in retrospective detail. These phenomena include the dangerous, such as hurricanes, tornadoes, and clear air turbulence; the broadly significant, such as ENSO, droughts, floods; the unexpected, such as volcanoes and regional fires; and the economically significant, such as agricultural conditions and flight weather.

Current polar satellites will not provide the spatial resolution or measurement range and precision appropriate for improved numerical weather forecasting. Advances in computer processing power should be taken for granted over the next 15 years. Advances in understanding the underlying chemistry and physics of the atmosphere are coming from existing studies, and should accelerate with the availability of US and international EOS experimental results. Together, the computers and their algorithms must be fed with significantly more and better operational sensor data to fulfill the promise of better environmental forecasts.

Quantitative benefits can be estimated from some aspects of satellite data improvements, in terms of dollars or lives affected. The most difficult part is estimating the quantitative change in information products attributable to a specific change in sensor data quality. The OSSEs will provide the deterministic answer. For now, expert estimates have been used.

A second problem with benefit estimation is the large number of small societal benefits from weather satellites. The increase in these from improvements in the satellites are totally lost in the day-to-day economic "noise", but they are no less real.

This study has included four economic case studies with annual benefits in the order-of-magnitude range from millions to tens of millions of dollars (Table 3-1). The Catalog in Appendix C lists about 80 benefit applications, leading to a rough order-of-magnitude benefit estimate of $100 million per year.

By way of comparison, a National Institute of Standards and Technology (NIST)[46] study concluded that the annual value of NWS weather forecasts to the public in 1992 was $4B, and to industry was $7B, or about $4.7B and $8.2B in 1998 dollars[47]. If NPOESS adds 1% to the overall value of weather information, its economic benefit would be about

$$1\% \times (\$4.7B + \$8.2B) = \$130 \text{ million per year.}$$

This rough agreement (around $100 million per year in benefits) represents only a part of the socioeconomic benefit. First, the $130M does not include economic benefits unrelated to weather, such as ocean color and land imagery. It does not include the increased reliance which can be placed on improved forecasts, and therefore the greater efficiency of decision making. It does not include the quality of life issues associated with having more confidence in the weather in the near future. More importantly, it does not include the value of a more solid information basis on which important environmental policy decisions can be made. These decisions include current anthropogenic changes, such as chlorofluorocarbons (CFCs), carbon dioxide, deforestation, and pollution; as well as unforeseen ones in the future. Future policy issues will only be approached intelligently and with minimum societal disruption if an improved knowledge base is begun now.

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[46] Chapman, Robert E., Benefit-Cost Analysis for the Modernization and Associated Restructuring of the National Weather Service, National Institute of Standards and Technology, Report NISTIR-4867, July 1992

[47] based on 17% CPI increase '92 to '98

Appendix A: NPOESS EDRs

See TRD Appendix D for current EDRs.

Appendix B. Interview Summaries

This appendix lists interviews held in 1997 with NOAA Product Oversight Panel (POP) representatives, and others who were able to discuss product applications. Notes and surveys taken in connection with this study have been collected by the IPO.

Date	Experts	Topic
28 August	Selina Nauman, NOAA/Nat'l. Ice Center Bruce Ramsay, NESDIS OSDPD	snow & ice data
28 August & 18 September	CDR Don Taube, USN, Naval Ice Center	ice data
18 September	Dudley Bowman, OSDPD	ozone data
18 September	John Sapper, NESDIS	radiation budget and SST
23 September	Steve Lord, NCEP	numerical weather forecasting
23 September	Ken Mitchell, NWS	snow data
23 September	Bill Pichel, NESDIS, ORA	SST data
23 September	Larry Flynn, NESDIS (?) Walter Planet, NESDIS	ozone
24 September	Herb Jacobowitz, NESDIS/ORA	radiation budget
06 October	Ellen Brown, NESDIS Mitch Goldberg, NESDIS Tom Kleespies, NESDIS Larry McMillan, NESDIS	sounder
06 October	Chris Duda, NESDIS/SP Larry Stowe, NESDIS/ORA	clouds & aerosols
07 October	Ralph Ferraro, NESDIS	precipitation
24 October	Mel Gelman, NWS/NP Jim Miller, NWS/NP	stratosphere and upper atmospheric ozone

24 October	John Janowiak, NWS/NP Herb Jacobowitz, NESDIS/ORA	SST & radiation budget
24 October	??	SST applications
24 October	Chin-Lin Zhao, NWS/NP Ken Campana, NWS/NP	Environmental Modeling Center
31 October	Mike Rossetti, DoT Volpe Center	transportation applications
06 November	Paul Polger, NWS/OM Charles Kluepfel, NWS/OM	validation and skill
17 November	Grayson Wood, NMF	CoastWatch
26 November	Dave Witchey, UAL, Chicago	aviation planning
18 December	Mike Craig, USDA	National Agricultural Statistics Service
19 December	Mike Gerber, NWS/Boise	fire weather

Appendix C. Catalog of Civil Benefits

The catalog contains brief summaries of civil benefits which may result from improvements in polar satellite sensor performance. It is a work-in-progress, in the sense that the IPO study of civil benefits is not complete, and in the sense that the general understanding of the relationship between environmental sensing and socioeconomic benefits is not well understood.

The first part identifies each enumerated benefit. It is placed in one of four categories, depending on whether its impact is mainly economic or societal, direct or indirect. Only direct economic benefits have been considered for evaluation in this study, since the other categories have problems of measurement too difficult for its scope.

Individual catalog entries are described here:

ID: A detailed breakdown of the application classification scheme is given in Table C-2.

Area: Broad classifications

Application: Narrower classifications

Element: Specific aspect of the application which benefits from environmental information

Benefit: Manner in which the element benefits

Environmental Factors: Aspects of environment which influence the Element

Term: The following initial letters are used to suggest typical minimum lead times for useful information value. Multiple letters show that there may be different benefits with different lead times.

<u>H</u>istory	<u>M</u>edium (3 day)
<u>O</u>bservation	<u>L</u>ong (10 day)
<u>S</u>hort (1 day)	<u>C</u>limate (30 day)

EDRs: Those which contribute to this benefit.

The key to EDR numbers is found in Table C-1.

In many cases, "NWF" is used for to stand for numerical weather forecasting, which will benefit from numerous EDR improvements, especially key parameters, sounders, surface boundary conditions, and radiative balance. As used here, it also includes the application of meteorologists' skill to the same EDRs in local or short-term forecasting problems, as facilitated by new information technologies, such as the Advanced Weather Interactive Processing System (AWIPS).

Process: Discussion or notes on the method by which a benefit arises from improved environmental monitoring.

References: *(cross-references not yet included)*

The second part is found in Table C-4. It is a semiquantitative to estimate each application's importance.

The expected benefit is the product of several factors:

- Economic importance of the activity or application
- Relevance of environment to the activity
- Relevance of environmental information (forecast, observation, history) to the environmentally-sensitive component
- Relevance of polar improvements to appropriate environmental information.

Each of these has been scaled 1 (lowest) to 4 (highest), and color coded red (lowest), yellow, green, blue (highest). White represents "no estimate". The higher-rated (bluer) an application is in all factors, the more significant is its potential economic benefit from improved polar sensor data.

Table C-1. EDR reference summary

Key Environmental Performance Parameters

1. Atmospheric Vertical Moisture Profile
2. Atmospheric Vertical Temperature Profile
3. Imagery (visible, infrared, microwave)
4. Sea Surface Temperature (SST)
5. Sea Surface Winds (Speed and Direction)
6. Soil Moisture (Surface)

Atmospheric Parameters

7. Aerosol Optical Thickness
8. Aerosol Particle Size
9. Ozone Total Column/(Profile, Objective)
10. Precipitable Water
11. Precipitation Type/Rate
12. Pressure (Surface/Profile)
13. Suspended Matter
14. Total Water Content

Cloud Parameters

15. Cloud Base Height
16. Cloud Cover/Layers
17. Cloud Effective Particle Size.
18. Cloud Ice Water Path
19. Cloud Liquid Water
20. Cloud Optical Depth/Transmissivity
21. Cloud Top Height
22. Cloud Top Pressure
23. Cloud Top Temperature

Earth Radiation Budget Parameters

24. Albedo (Surface)
25. Downward Longwave Radiation (DLR) (Surface)
26. Insolation
27. Net Shortwave Radiation (TOA)
28. Solar Irradiance
29. Total Longwave Radiation (TOA)

Land Parameters

30. Land Surface Temperature
31. Normalized Difference Vegetation Index
32. Snow Cover/Depth
33. Vegetation Index/Surface Type

Ocean/water Parameters

34. Currents
35. Fresh Water Ice.
36. Ice Surface Temperature.
37. Littoral Sediment Transport
38. Net Heat Flux
39. Ocean Color/Chlorophyll
40. Ocean Wave Characteristics
41. Sea Ice Age/Sea Ice Edge Motion
42. Sea Surface Height
43. Surface Wind Stress
44. Turbidity

Space Environmental Parameters

45. Auroral Boundary
46. Auroral Energy Deposition, Total
47. Auroral Imagery
48. Electric Field
49. Electron Density Profiles/Ionospheric Specification
50. Geomagnetic Field
51. In-situ Ion Drift Velocity
52. In-situ Plasma Density
53. In-situ Plasma Fluctuations
54. In-situ Plasma Temperature
55. Ionospheric Scintillation
56. Neutral Density Profiles/Neutral Atmospheric Specification
57. Radiation Belt and Low Energy Solar Particles
58. Solar and Galactic Cosmic Ray Particles
59. Solar Extreme Ultra Violet (EUV) Flux
60. Supra-thermal through Auroral Energy Particles
61. Upper Atmospheric Airglow

Potential Pre-planned Product/Process Improvements

62. Tropospheric Winds
63. Ozone Profile - High-Resolution
64. CH_4 (Methane) Column
65. CO (Carbon Monoxide) Column
66. CO_2 (Carbon Dioxide) Column
67. Optical Backgrounds
68. Bathymetry (Deep Ocean and Near Shore)
69. Bioluminescence
70. Salinity

Table C-2. Index to catalog benefit types and applications

Benefit Type	Application Area		Cat. ID
Civil Protection: Life; Health-injury; Property damage (direct, non-$$)	general		1.00
	severe storm	tornadoes	1.01
		high winds	1.02
		snow	1.03
		tropical storms	1.04
	flood	coastal	1.05
		river	1.06
	droughts		1.07
	heatwave/extreme cold		1.08
	pollution		1.09
Economic activity (direct, $$)	agriculture		2.01
	fisheries		2.02
	forestry, land/range management		2.03
	river management		2.04
	fossil fuel production & distribution		2.05
	manufacturing & retail		2.06
	construction		2.07
	transportation	air	2.08
		ocean	2.09
		land	2.10
		space	2.11
	utilities	general	2.12
		water	2.13
		electricity	2.14
		communications	2.15
	recreation		2.16
	environmental information	finance	2.17
		insurance	2.18
		commodities	2.19
		weather (industry)	2.20
	government operations		2.21
Public Policy; Understanding Earth (indirect)	environmental policy		3.01
	Earth processes		3.02
	model evaluation		3.03
	global change		3.04
Societal Benefits (indirect)	quality of life		4.01

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
1.04.1	Civil Protection	Tropical cyclone warnings	Proper evacuation warnings for gale winds (>34 mph), storm surge flooding, rain flooding	Avoid unneccessary evacuation: begin evacuation in time to complete before either gale wind, storm surge arrives	Gale wind radius (surface); eye track; QPF	S	NWF, 3	evacuation cost is ~$640k/mi. (OFCM, 1997, p. 2)
1.05.1	Civil Protection	Coastal flooding		accurate flood warning; loss mitigation	storms; sea surface winds; inshore bathymetry; coastline changes	S-M	NWF, 5, 34, 40, 43	
1.06.1	Civil Protection	Riverine flooding		accurate flood warning; loss mitigation	snowmelt forecast; precipitation forecast	S-M	NWF, 3, 30, 32	
1.08.1	Civil Protection	Heat/cold emergencies	Warnings to emergency services	life and health	temp, humidity, wind prediction	S-M	NWF, 7	
1.00.1	Civil Protection	Severe storm warnings	Timely protection	loss mitigation	severe storms	S	NWF, 3	
1.00.2	Civil Protection	Severe storm warnings	Reduce false alarm rate	cost reduction	severe storms	S	NWF, 3	
1.09.1	Civil Protection	Air pollution emergencies	Warnings to emergency services	life and health	temp, inversion, insolation (incl. UV), wind	S-M	NWF, 7	
1.09.2	Civil Protection	Water pollution emergencies	chemical and biological hazard tracking	life and health	inshore circulation; ocean color; sea surface wind	O-S	NWF, 34, 39, 40, 43, 44, 69	
2.01.1	Agriculture	Pre-season	Crop selection	best yield	all growing environment	L	NWF, 31, 33	proper crop selection based on (a) anticipated seasonal local growing conditions, and (b) anticipated seasonal forecasts over the market area

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.01.3	Agriculture	Spraying	specific protection needs	least cost	temp, humidity, precip prediction	M	NWF	decide what pest & desease should be anticipated
2.01.4	Agriculture	Spraying	application conditions	best application time	wind, temp, precip prediction	S	NWF	decide when during range of best application time will wind, temp, & precip be proper
2.01.5	Agriculture	Harvesting	crop readiness	best yield	temp, precip, insolation (PAR)	M	NWF, 31,33	plan harvest with crop maturity
2.01.6	Agriculture	Harvesting	harvest, drying conditions	avoid loss	precip, wind prediction	M	NWF	plan harvest with proper env conditions
2.01.7	Agriculture	Frost	bud loss; crop loss	avoid loss	ground temp, inversions, surface humidity, wind, radiative cooling	S	NWF, 1,2,3	decide whether frost mitigation efforts are needed and likely to be effective; harvest before frost
2.01.8	Agriculture	Market conditions	crop planting & yield, livestock worldwide: competitive intelligence	produce value prediction	landuse analysis; yield analysis	L-C	NWF (world wide), 31-33	Predicting global crop market conditions
2.01.9	Agriculture	Animal management	livestock, poultry heat stress	best yield	temperature, humidity, wind	M	NWF	decide whether to move or butcher before heat-, drought-induced losses
2.01.10	Agriculture	Animal feeding	grass, hay, silage, feed availability; rangeland suitability	reduce feeding cost	landuse analysis; yield analysis	L-C	31, 33	decide whether grass or alternative feed is needed
2.01.11	Agriculture	Transportation demand	resource scheduling	optimal planning for transportation resources from farm/ranch to market	geo, time distribution of yield prediction	L-C	NWF, 31	waste avoidance; decisions among truck, rail, barge, ship; elevators and stockyards
2.02.1	Fisheries	fising ship operation	fishery location; fishery regulation	efficient operation under regulation	primary productivity, temperature, ice edge location, ocean current location, sea state	M	4, 34, 39, 40, 41, 43, 44, 69	

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.02.2	Fisheries	fish farming	farm location selection	match location to species	salinity, pollution, turbidity	M	34, 39, 40, 44, 69,70	requires improved near-shore resolution
2.03.1	Land management	Forest, range fire	firefighting resources; use permits; health hazards	firefighter safety; minimize fire damage; minimize firefighting cost	soil moisture; canopy moisture; landcover classification; wind; dessication	S-M	NWF, 3, 6, 11, 26, 30, 31, 32, 33	fire danger indices require soil moisture, and drying, wetting phenomena
2.03.2	Land management	Forest, range fire	controlled burns	intelligent planning; frefighter safety; minimize cost	soil moisture; canopy moisture; wind; dessication	O-L	NWF, 3, 6, 11, 26, 30, 31, 32, 33	pre-planned burns additionally require accurate predictions of wind direction & precipitation
2.03.3	Land management	Erosion	prevention; remediation		soil moisture; precip prediction; landcover classification			(TBD)
2.03.4	Land management	Space remote sensing	Cloudcover avoidance	efficient utilization of fixed-cost system; maximum information for the user community	Cloudcover	S	NWF	Landsat is Gov't operated system. Operating costs and collection capacity are approx. fixed. More saleable scenes. Worldwide requirement.
2.04.1	River management	Dams	Level/flow control	power generation, water supply, irrigation, flood control, navigation	River flow prediction from QPF, soil moisture, snowcover & melt	M-L	NWF, 6, 32	Hydrological prediction is dependent on knowing the current ground saturation & temperature, the snowmelt potential, the temperature/wind/insolation environment which causes snowmelt, and predicted precipitaiton within a basin.
2.05.1	Fossil Fuels	Fuel distribution/ production planning	refinery production		heating/ cooling degree days prediction; transportation demand factors	L	NWF	optimum decision making in crude oil purchasing & refinery production planning

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.05.2	Fossil Fuels	Crude oil pipeline operations (esp. Alaska)	crude oil heating limits for efficient flow	delivery cost reduction	temperature; wind	S	NWF, 20, 32	crude must be optimally warmed for pipeline pumping in Alaska
2.05.4	Fossil Fuels	Marine oil spills	cleanup	knowing spread direction & proper recovery equipment	wind; wave height; currents	O-S	NWF, 4, 5, 34, 40, 43	
2.05.6	Fossil Fuels	Offshore oil & gas production	Offshore operations	facility evacuation; lightering; maintenance	storm warnings; wind/wave conditions	S	NWF, 40	planning for crew & equipment transfers to platforms; proper operations/evacuation decisions
2.05.7	Utilities	Natural gas distribution/production planning	advanced fuel purchase commitments	optimum decision making in purchase, production planning for fossil fuels	heating/cooling degree-days prediction	C	NWF	
2.06.2	Retail	Inventory planning	weather-sensitive inventory	right food, merchandise for the weather	all	M-L	NWF	right merchandise at the right time while minimizing inventory size & inventory loss
2.06.3	Retail	Delivery	schedule; loss of perishables	proper staff for timely delivery	Storms; extreme temperature	S	NWF	
2.07.1	Construction	concrete construction	pouring and curing	premirum cost, rework avoidance	low temperature; precipitation; humidity	S	NWF	scheduling; proper concrete selection
2.07.2	Construction	Exterior work; site preparation		worker efficiency	high wind; low temperature; precipitation	S	NWF	resequencing crafts appropriate to the weather; calling in only those crafts who can work under anticipated conditions; equipment to keep the site open; materiel scheduling
2.08.1	Air Transportation	Flight disruptions	cancellation; diversion; significant delay	trip disruption; housing, labor cost; bussing cost; lost revenue	severe weather	S	NWF	understanding severe weather which compromises system performance at airports

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.08.2	Air Transportation	Dynamic utilization adjustment	equipment & crew redispositioning	reduce operating cost	severe weather	S-M	NWF	peparing for severe storms which may strand equipment or crews
2.08.5	Air Transportation	Search & rescue	detection; location; rescue	safety	offshore wind, visibility, waves	O	NWF, 4, 5, 16, 40, 41	Know the conditions at a rescue site before escue craft arrive.
2.08.6	Air Transportation	Routing	equipment damage	avoid volcanic ejecta	detection (dust, SO2); winds aloft	S	NWF, 3, 7, 8	avoid chemical and particulate damage to engines, a/c
2.09.1	Ocean Transportation	Ship routing	equipment utilization; delivery of perishables	route optimization	ocean currents; sea surface winds; sea ice; sea state	S-M	4, 5, 34, 35, 40, 41, 42	identify route which optimizes transit time or fuel efficiency
2.09.2	Ocean Transportation	Safe navigation	death & injury risk; equipment damage	severe weather avoidance	storms; sea ice; sea state; aerosols (dust, fog)	S	NWF, 5, 7, 8, 40	avoid potential problems, based on ship capabilities
2.09.3	Ocean Transportation	Icebreaking	icebreaking efficiency; route optimization	icebreaker operations; efficient route	Ice thickness, classification	O	3, 35, 36, 41	identify open areas, weak ice for efficient icebreaker operations
2.09.4	Ocean Transportation	Port & harbor operations	Access; loading efficiency	lengthened seasons; economic operations	wind; wave state; ice	O	3, 4, 5, 40, 43	improved imager resolution permits remote evaluation of more/smaller ports
2.10.1	Hwy Transportation	Snow/ice clearing	crew/equip scheduling; spreader material selection	efficient equipment disposition; false alarm avoidance	precip type & quantity prediction; thaw prediction	S	NWF, 30, 32	
2.10.2	Hwy Transportation	Truck routing		route optimization	storms	S	NWF	choose optimum route among stops given anticipated storm delays
2.10.3	Hwy Transportation	Personal vehicles	trip planning	safety; delay avoidance	storms; freezing	M	NWF	choose optimum route among stops given anticipated storm delays
2.11.2	Space transportation	Landing	prime & alt. landing sites	improved crew safety; cost avoidance	wind (all alt.); clouds/precip/atm. electricity	O-S	NWF, 15, 16, 62	correctly forecast when landing criteria will be met

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.12.1	Utilities	Distribution plant	Above-ground plant	rapid, efficient service restoration	high winds; prob. of lightning; ice storms	S	NWF	improved preplacement/ deployment of crews, equipment, parts for service restoration
2.13.1	Utilities	Water supply	distribution	improved water use planning	dessication: wind, temperature, humidity, insolation	S-M	NWF	predict demand
2.13.2	Utilities	Water supply	reservoir, riverflow prediction	proper selection among alt sources (surf water or pumped aquifer): cost & conservation benefits	QPF; seasonal forecasts	M-L	NWF, 32	predict supply
2.14.1	Utilities	Power production planning	equipment, staff scheduling; load sharing; pumped storage	reduced production cost using less, more efficient generating capacity	heating/cooling degree days; wind; sunlight hours	S	NWF	load sharing across network based on optimal available equipment for anticipated load:
2.14.2	Utilities	Power production planning	hydro power	maximize use	precipitation, snowmelt	M	NWF, 32	optimization of hydropower planning, based on water availability and power demand
2.14.3	Utilities	Electric power distribution	line carrying capacity	increased distribution capacity; cheap power availability	temperature, wind	S	NWF	optimum transmission line utilization based on cooling rate
2.14.4	Utilities	Electric power distribution	Flare-induced grid overload	prevent equipment damage	space environment	S	SES	warning permits reconfiguration
2.14.5	Utilities	Maintenance planning	equipment offline	efficient operation	energy load prediction	M-L	NWF	taking equipment offline when least needed (electric, also natural gas, petroleum)
2.15.1	Communication	RF propagation	ground-ground		space environment	S-M	SES	
2.15.2	Communication	RF propagation	ground-space		space environment	S-M	SES	

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.15.4	Communication	Service restoration	outside plant: prepositioning facilities repair personnel & equipment	reduced outage time to users; reduced cost to providers	storm location, severity	S	NWF	improved preplacement/ deployment of crews, equipment, parts for service restoration
2.16.1	Recreation	Outdoor activities	staff scheduling; facilities scheduling; seasonal opening/ closing	utilization efficiency; user planning	temperature, wind, precipitation, cloudcover, surf	M-L	NWF	reduction in staffing margin, errors; improved seasonal decisions (e.g., skiing, golf, parks, beaches)
2.16.2	Recreation	Recreation activity selection (e.g. beach conditions)	suitability	opportunity cost of bad decisions - lost time equiv.	temp, humidity, cloudcover, wind precip; lightning hazard	S	NWF	
2.16.3	Recreation	Boating	safety	boater safety; government rescue costs	surface wind, wave state	S	NWF, 5, 40, 43	
2.19.1	Environmental information	Economic markets	informed decision-making	efficient market forces	energy demand; agricultural environmental parameters; transportation forecasts	L	NWF	
2.20.1	Environmental information	Commercial information dissemination	Media weather information	increased value to media	all	S-M-L	NWF	more accurate, timely, precise data leads to increased forecast accuracy, more information content, more value to the public
2.20.2	Environmental information	Commercial information dissemination	private weather information	expansion of private industry	all	S-M-L	all	more accurate, timely, precise data leads to increased opportunities for private weather industry
2.21.1	Government operations	Facility closings	gov't, business closings	reduce lost productivity	precipitation, temp forecasts (esp. timing)	S	NWF	

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
2.21.3	Government operations	police, fire, public works	routine resource deployment: shift assignments, overtime	efficient staff utilization	temperature, storms	S	NWF	certain weather conditions increase demand on public safety staff
2.21.4	Government operations	Management oversight	national polar sat weather programs	reduced cost	n/a	n/a	n/a	NPOESS' design reduces cost to Gov't to operate the polar constellation
2.21.5	Government operations	School, daycare operations	school closing decisions	avoid improper closing decisions	temperature; precipitation quantity & type	S	NWF	Efficient school operations; reduced lost work by parents
3.01.1	Public policy	Policy planning	Information for environmental policy development			H-O	most	detect areas of environmental stress or resiliency: land, ocean, atmosphere
3.01.2	Public policy	Policy planning	Information for agricultural policy development			H-O	most land & atmosp here	correlation between environmental growth factors and yields
3.01.3	Public policy	Policy planning	Information for land develpment, housing policy planning		Landcover & landuse trends, ecosystems sensitivity	H-O	3, 6, 31-33	precise inventory of land use dependencies
3.02.1	Understanding Earth	Environmental database development	Continue the 30 year polar sensor database	better basis for decision making	all	H	all	
3.02.3	Understanding Earth	Environmental model development; process studies	Teleconnections	better understanding of environmental relationships and processes; improved forecast models	all surface, atmosphere, and external energy sources	H	all	ENSO is a case of environmental changes in one region affecting others. Data must be available to identify and use other, more subtle, land-ocean-air mechanisms operating over the globe with periods from seasons to years.

ID	Area	Application	Element	Benefit	Environ-mental Factors	Term	EDRs	Process / Discussion
3.02.3	Understanding Earth	Environmental model development; process studies	Forecast algorithm development	improved forecasts; increased public confidence in forecasts	all surface, atmosphere, and external energy sources	H	all	more precise measurements w ill permit
4.01.1	Society	Weather forecasting	Practical knowledge	being informed, prepared for local conditions	temp, humidity, cloudcover, wind, precipitation, UV index	O-S-M-L-C		
4.01.2	Society	Business travel	transp planning; clothing carried	efficiency and comfort		S-M		
4.01.3	Society	Recreation/ leisure travel				S-M		

Table C-4. Significance of applications

Catalog	Name	Economic Importance	Relevance		
			Environment	Information	Improvements
Data not yet available					

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Appendix D. Related NOAA/NASA Research

The following examples have been selected from the current NOAA grants list. They are representative of the kind of grant research supported by NOAA which helps to understand the relationships among environmental sensing, environmental processes, and socioeconomic benefits. The list does not include the substantial resources which NOAA commits to broad-based joint research institutions and laboratories, nor to the Sea Grant program, which also supports progress in relevant environmental understanding. It also does not include support by other agencies, such as NASA, NSF, DoE, and DoD.

ST	Recipient / Grant #	NOAA Share $	Project Title
AL	University of South Alabama NA77FD0077	68,750	MONITORING THE SOCIO-ECONOMIC IMPACTS OF FEDERAL REGULATIONS ON GULF OF MEXICO COMMERCIAL SHRIMP FISHERMEN
AZ	The Arizona Board of Regents NA76GP0557	80,224	EVALUATION OF GCM LAND-SURFACE AND NEAR SURFACE ATMOSPHERIC SCHEMES IN GCIP
AZ	University of Arizona NA76GP0385	140,173	THE SOCIAL POLICY IMPLICATIONS OF SEASONAL FORECASTING: A CASE STUDY OF CEARA, NORTHEAST BRAZIL
CA	San Diego State University Foundation NA77EC0131	325,091	IN SITU BIO-OPTICAL MEASUREMENTS FOR ALGORITHM DEVELOPMENT AND VALIDATION IN SUPPORT OF THE EOS MODIS EXECUTION PHASE.
CA	Univ. of California NA46GP0244	65,228	HYBRID AND INTERMEDIATE COUPLED MODELING OF THE OCEAN-ATMOSPHERE-LAND SYSTEM
CA	Univ. of California NA56GP0203	88,730	DIAGNOSTIC STUDY OF THE GLOBAL OCEAN-ATMOSPHERE-LAND SYSTEM--VARIABILITY OF PLANETARY-SCAE MONSOONS
CA	Univ. of California NA56GP0451	135,030	PREDICTABILITY STUDIES FOR THE OCEAN-ATMOSPHERE-LAND SYSTEM
CA	University of California NA66GP0275	40,000	ACCURATE DETECTION OF PATTERNS OF SPATIAL AND TEMPORAL CHANGE IN SATELLITE, MODEL AND IN SITU DATA USING NEW MULTI-VARIATE STATISTICAL TRANSFORMATION
CA	Univ. of California NA66GP0401	28,531	JIMO TASK IV- INTEGRATED USE OF GOES, GVAR AND NOAA POLAR ORIBITER SATELLITE DATA IN OPERATIONAL WEATHER FORECASTING
CA	Univ. of California NA76GP0423	101,990	AIR-INTERACTION STUDIES OF THE TROPICAL INDO-PACIFIC SEAS USING DATA FUSION METHODS ON MULTI-SATELLITE AND SITU OBSERVATIONS
CA	Univ. of California NA76GP0451	19,941	IMPROVED CLIMATE FORECASTS AND PACIFIC RIM GRAIN SUPPLY AND MARKETS
CA	Univ. of California NA76GP0482	60,000	CUMULUS CONVECTIVE TRANSPORT OF CHEMICAL TRACERS: CLOUD MODELING AND PARAMETERIZATION

ST	Recipient / Grant #	NOAA Share $	Project Title
CA	Univ. of California NA66GP0340	164,810	OCEAN COLOR ASSESSMENT OF PLUMES AND BLOOMS IN THE SANTA BARBARA CHANNEL AND ITS SURROUNDING WATERS
CO	The Regents of the University of Colorado NA56GP0230	421,118	PREDICABILITY OF THE COUPLED OCEAN-ATMOSPHERE SYSTEM OF INTRASEASONAL AND INTERANNUAL TIME SCALES
DC	National Safety Council NA76GP0534	60,002	WEATHER AND CLIMATE IMPACTS: REGIONAL BACKGROUNDS
DC	Science and Policy Associates, Inc. NA66GP0253	128,600	AN INTEGRATED ASSESSMENT OF THE SOCIAL AND ECONOMIC EFFECTS OF EXTREME CLIMATIC FLUCTUATIONS ON FORESTS IN THE NORTHEASTERN UNITED STATES.
FL	Florida State University NA76GP0521	500,000	REGIONAL ASSESSMENT OF ENSO IMPACT IN SSA AND SNA TO CONTINUE THE CENTER FOR OCEAN-ATMOSPHERIC PREDICTION STUDIES AS A NOAA APPLIED...
IL	Board of Trustees, University of Illinois NA66GP0445	35,000	TEMPORAL FLUCTUATIONS IN FLOOD-PRODUCING PRECIPITATION EVENTS AND ASSOCIATED CIRCULATION PATTERNS
IL	Board of Trustees, University of Illinois NA56GP0455	47,000	INFLUENCE OF AEROSOL PARTICLES ON CLIMATE AT A MID-LATITUDE CONTINENTAL SITE
IL	Board of Trustees, University of Illinois NA76GP0293	20,509	AEROSOL LIGHT SCATTERING AND RELATED PROPERTIES AT CLIMATE SENSITIVE SITES (ACE-2)
IL	Board of Trustees, University of Illinois NA76WP0274	293,334	MIDWESTERN CLIMATE CENTER: SERVICE AND APPLIED RESEARCH
IL	University of Chicago NA56GP0370	62,369	HUMAN-CLIMATE INTERACTIONS IN THE LAKE TITICACA BASIN OF BOLIVIA
LA	La. Dept. of Wildlife and Fisheries NA76FK0429	2,500,000	MONITORING THE IIMPACT OF ENVIRONMENTAL PERTURBATIONS ON COMMERCIAL FISHERMEN
MA	Atmospheric and Environmental Research, Inc. NA76GP0398	35,000	DYNAMIC AND THERMODYNAMIC FACTORS AFFECTING SUMMERTIME
MA	Cambridge Medical Care Foundation NA56GP0623	90,000	HUMAN HEALTH AND ECONOMICS DIMENSIONS OF CLIMATE FLUCTUATIONS
MA	Cambridge Medical Care Foundation NA56GP0623	12,000	HUMAN HEALTH AND ECONOMICS DIMENSIONS OF CLIMATE FLUCTUATIONS

ST	Recipient / Grant #	NOAA Share $	Project Title
MA	Harvard University NA56GP0360	73,709	CLIMATE-HUMAN INTERACTIONS IN THE LAKE TITICACA BASIN OF BOLIVIA
MD	Institute of Global Environ. & Society, Inc. NA76GP0258	1,200,000	PREDICTABILITY OF THE PRESENT CLIMATE
MD	University of Maryland, College Park NA66GP0306	75,000	NEW GEOPHYSICAL PARAMETERS FOR IMPROVING GLOBAL MODELING OF THE HYDROLOGICAL CYCLE AND NEW PRIMARY PRODUCTIVITY
MN	University of Minnesota NA76GP0240	56,996	COLD SEASON PBL-SURFACE INTERACTIONS: FORESTS AND FARMLANDS
NJ	Rutgers, the State Univ. of New Jersey NA76GP0522	59,680	VALIDATION OF OLD AND NEW SATELLITE GLOBAL SNOWCOVER PRODUCTS
NY	Research Fdn. of State University of New York NA76GP0450	46,619	REMOVING SATELLITE EQUATORIAL CROSSING TIME BIASES FROM THE GLOBAL OUTGOING LONGWAVE RADIATION DATA SET
OR	Nat. Coastal Resources Research & Devel. Inst. NA76RG0163	950,000	TECHNOLOGY TRANSFER/PROJECT DEMONSTRATION FOR STRENGTHENING US COASTAL ECONOMICS
OR	Pacific States Marine Fisheries Commission NA67FN0460	200,000	SPECIFICATION AND IMPLEMENTATION OF A SYSTEM TO PROVIDE DATA NEEDED FOR ECONOMIC ANALYSES OF WEST COAST FISHERIES
OR	Pacific States Marine Fisheries Commission NA77FN0486	233,793	PACIFIC COAST MARINE RECREATIONAL FISHERIES 1998 ECCONOMIC SURVEY
PA	The Pennsylvania State University NA77WA0566	212,718	USE OF SATELLITE PRECIPITATION PRODUCTS FOR REGIONAL QUANTITATIVE PRECIPITATION FORECASTING WITH THE PSU/NCAR MESOSCALE MODEL
TX	Texas A&M Research Foundation NA77FD0076	46,389	DEVELOPMENT OF MICROSATELLITE LOCI FOR STOCK STRUCTURE STUDY OF GULF RED SNAPPER
TX	Texas A&M Research Foundation NA77FF0551	73,712	THE STRUCTURE AND ECONOMICS OF THE CHARTER AND PARTY BOAT FISHING FLEETS OF TEXAS, LOUISIANA, MISSISSIPPI, AND ALABAMA.
TX	Texas A&M University - TX Agricultural Exp St NA66GP0189	83,539	EFFECTS OF SEASONAL CLIMATE FORECASTS ON THE COMPETITIVENESS IN THE GRAIN MARKET

Appendix E. Bibliography on the Socioeconomic Benefits Associated with Improved Weather Forecasts

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Acronyms

ALT	Altimeter
ASOS	Automated Surface Observation System
AVHRR	Advanced Very High Resolution Radiometer
AWIPS	Advanced Weather Interactive Processing System
BLM	Bureau of land Management
CMIS	Conical Microwave Imager Sounder
COBRA	Cost, Operational Benefit, and Requirements Analysis
CPC	Climate Prediction Center
CPI	Consumer Price Index
CrIMSS	Cross-track Infrared / Microwave Sounder Suite
DMSP	Defense Meteorological Support Program
DCS	Data Collection System
DOC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
EDR	environmental data record
EIA	Energy Information Administration
EMC	Environmental Modeling Center
ENSO	El Nino - Southern Oscillation
ERBS	Earth radiation budget sensor
EUV	extreme ultraviolet
F	Fahrenheit
FOM	figure of merit
G	giga-, billion
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
IORD	Initial Operational Requirements Document
IPO	Integrated Program Office
K	degree kelvin
kWh	kiloWatt-hours
NCEP	National Centers for Environmental Prediction
NEXRAD	Next-Generation Radar (WSR-88D)
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NPOES	National Polar-orbiting Operational Environmental Satellite
NPOESS	NPOES System
NRCS	Natural Resources Conservation Service
NWF	numerical weather forecasting
NWS	National Weather Service
OAR	Office of Atmospheric Research
OLS	Operational Line Scanner
OMPS	Ozone Mapper-Profiler Suite
ORA	Office of Research and Analysis
OSSE	observing system simulation experiment
POES	Polar-orbiting Operational Environmental Satellite
POP	Product Oversight Panel
Q	humidity
RH	relative humidity
SARSAT	Search And Rescue - Satellite
SES	Space Environment Suite

T	temperature
TOA	top of atmosphere
TSIS	Total Solar Irradiance Sensor
URL	uniform resource locator
USFS	US Forest Service
USGS	United States Geologic Survey
VAR	value-added reseller
VIIRS	Visible/Infrared Imager/Radiometer Suite
WFO	Weather Forecast Office
WMO	World Meteorological Organization

Definitions

El Nino - Southern Oscillation (ENSO): a coupled set of phenomena associated with a multi-year Pacific Ocean oscillation, and the resulting climate changes due to ocean-atmosphere coupling.

phytoplankton: simple surface plants which form the bottom of the ocean food chain; compare with "zooplankton", which are simple animals.

rawindsonde: an instrumented upper atmosphere balloon which is used to measure, temperature, humidity, pressure, and wind profiles from the surface.

teleconnection: a climate connection between observed events in one location and changes in weather at another, such as the ENSO effect on African drought.